Bolt Beranek and Newman Inc.

Report No. 3965

# Sound and Vibration Characterization of Canes for the Blind

Eric E. Ungar

November 1978

Prepared for:
American Foundation for the Blind, Inc.

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# ABSTRACT

With the aid of two instrumented canes wielded by two blind trained cane-users, recordings were made of the sounds at the user's ear and the cane vibrations at his hand. It was found that the auditory information provided by the canes generally is above the threshold of hearing, but is often masked by ambient noise. It was also found that the cane vibrations at frequencies below 250 Hz generally were above the threshold of vibrotactile perception, but that the higher-frequency vibrations were below that threshold. Cane-to-cane differences in the shapes of the sound spectra and of the vibration spectra were found to be greater than user-to-user differences. This observation, together with the expectation that a person's discrimination between different auditory and vibrotactual stimuli is related to differences in the associated spectrum shapes, served as the basis for development of related laboratory tests and their interpretation.

The laboratory test procedures that were devised involve measurement of cane handle vibrations and of sound at the approximate position of a user's ear as the cane tip is made to slide along test surfaces or to impact against such surfaces. A pendulum arrangement was found to be convenient for obtaining repeatable controlled impacts.

Evaluation measurements made in the laboratory on 22 different canes, of which two were tested with different tips, showed that canes with steel tips generally provide more auditory and vibrotactile information than canes with nylon tips. Canes with low bending stiffness appeared to be advantageous from the vibrotactile information viewpoint, whereas canes of acoustically "live" materials and configurations (which generate sound relatively readily when they are scraped) appeared to be advantageous from the auditory information viewpoint.

# SOUND AND VIBRATION CHARACTERIZATION OF CANES FOR THE BLIND

## 1. Introduction

In the early part of June 1978, representatives of the American Foundation for the Blind, Inc. (AFB) asked Bolt Beranek and Newman Inc. (BBN) to consider the problem of working out a simple and meaningful laboratory test procedure for evaluating the sound and vibration characteristics of the many different models of canes currently being supplied for use by the blind. AFB personnel pointed out that virtually nothing is known about how blind people use the vibrotactile and acoustical information that canes can provide, and that the problem of evaluating canes in relation to these characteristics apparently has not been addressed previously.

After some additional discussion, a program of investigations was developed with the aims of: (1) providing some initial understanding of the most important aspects of cane sound and vibration, and (2) obtaining related data on some of the most widely used canes.

It was decided to begin the program with measurement of the sound and vibrations that canes produce in actual use, so as to obtain quantitative data that could guide the development of meaningful laboratory tests. Accordingly, this in-use data was acquired first, with the aid of two instrumented canes and with the cooperation of two blind trained cane-users. As the result of analysis and interpretation of this data, there was developed a reasonable representation of the vibrotactile and auditory information these canes provide. Laboratory tests were then devised that essentially indicate a cane's capability for providing these types of information, and a selection of different canes was tested using these procedures.

The initial in-use cane tests and their results are discussed in Section 2 of this report; the laboratory tests and their results are summarized in Section 3.

## 2. Measurements on Canes in Use

### 2.1 Instrumentation

### 2.1.1 Test Canes

Two canes, whose dynamic characteristics were expected to differ greatly, were selected for this initial study: No. 3 was a collapsible cane made up essentially of four one-foot lengths of aluminum tube, with the lower 1-1/2-inch of each tube narrowed to a smaller diameter, so as to fit inside the adjacent tube; in use, the tube arrangement is held together by two rubber chords that run along the center of the cane. No. 17 was a noncollapsible cane consisting of a continuous 4-ft length of aluminum tube, with the end bent into a C-shape to form a handle. Cane No. 3 had a nylon tip; cane No. 17 a metal glide tip incorporating a rubber washer. The upper 10-inch length of each cane was enclosed in a tapered sleeve of soft rubber intended to provide gripping comfort.

### 2.1.2 Sensors and Data Recording

Each cane was outfitted with four miniature accelerometers (see Figure 1), weighing about 2 grams each. One accelerometer was mounted near the cane handle, on the metal just below the rubber grip, with its sensing direction perpendicular to the cane axis and located in the vertical plane when the cane is in use. The other three accelerometers were fastened to a 1/2-inch aluminum cube so that their sensing directions were mutually

perpendicular, and this cube was attached near the tip of the cane. These three accelerometers thus were arrayed to measure the axial, vertical and lateral motions of the cane tip. All attachments were made by use of a strong rigid epoxy.

The accelerometers that were used here were selected both for their lightness and for their built-in preamplifiers. Their small weight provided assurance that the sensors would not distort the cane motions appreciably. The built-in preamplifiers ensured that cable motions would not provide spurious signals.

The upper accelerometer was not placed on the rubber grip, because different grips may be expected to have different effects on the cane vibrations that reach the hand, and these effects are likely to vary with hand position, size of hand, and with the manner and strength of gripping--thus introducing additional variables that complicate data interpretation. Since rods are known to vibrate most readily in their radial directions, such a direction was selected for sensing. The specific direction used was selected for its ease of alignment, with the knowledge that at positions remote from impact points, rods generally exhibit about the same radial vibrations in all directions.

The triaxial accelerometer arrangement at the tip was chosen in order to determine the directions in which the primary cane tapping impacts occur, to measure the relative strengths of impacts in the three major directions, and to compare these to the vibrations that occur at the handle.

In the use-tests of these canes, a small microphone was placed at one ear of each user.

The signals from each accelerometer and the microphone were carried via light-weight cables to a pair of battery-operated

synchronized three-channel tape recorders. The sixth channel available on this pair of recorders was used for voice annotation, describing the test and noting the settings of the amplifiers and attenuators. Figure 2 indicates the recording instrumentation.

## 2.2 Cane Users

Two cane users, both trained by the Carrol Center for the Blind (Newton, Massachusetts), participated in these tests. Both were female and in their early to middle 50's.

One (Helen) had a small amount of sight, and claimed to have a minor hearing deficiency. She wore hard-heeled shoes and tended to make her heel impacts coincide with the cane taps. The other (Alice) had no sight, was aware of no hearing deficiency, and wore soft-heeled shoes that made no appreciable sound.

## 2.3 Data Acquisition and Reduction

### 2.3.1 Calibration of Instrumentation System

Before and after each test run, each accelerometer and data microphone channel was calibrated by subjecting each sensor to excitation of a precisely known magnitude. For the accelerometers, this was alone by means of a General Radio model 1557 vibration calibrator; for the microphone, this was done by use of a Bruel & Kjaer model 4220 pistonphone.

### 2.3.2 Data Acquisition Procedure

For each test run, the cane user was given an instrumented cane and was outfitted with a microphone. The user was then asked to walk "normally" along three outdoor and three indoor

areas, with the data acquisition engineer quietly walking behind, carrying the tape recorder, and with a third person walking along to keep the cables from becoming tangled.

In each test area, data recordings were made for several minutes under the best available ambient quiet conditions.

### 2.3.3 Test Areas

All test areas used were located on the premises of BBN at Cambridge. The outdoor areas were located behind BBN's 50 Moulton Street building and consisted of:

1. an asphalt driveway
2. a concrete walkway
3. a grassy lawn.

The indoor areas consisted of:

1. the cement floor in a large laboratory building
2. an asphalt tile floor in a corridor
3. a carpeted floor in a long corridor.

### 2.3.4 Data Reduction Instrumentation

The instrumentation that was used for reduction of the tape-recorded data is indicated in Figure 3. The real-time spectrum analyzer here is the key data reduction instrument; it enables one to display (on its cathode-ray screen) and evaluate a transient signal associated with a single impact and also permits one to obtain spectra (frequency distributions) for the averages of various numbers of such signals. An XY-recorder was used to provide plots of the desired spectra automatically. The speaker system shown in Figure 3 was used to monitor the voice annotation channel and to listen to the recorded audio signal (for background noise and other disturbances).

## 2.4 Results

### 2.4.1 Peak Accelerations; Differences Between Users and Canes

When a cane is tapped against a surface, the signal from any accelerometer rapidly rises to a peak, then drops off and oscillates with decreasing amplitude. Since the strength of the tapping impact may be characterized by the magnitude of this initial peak, a study of these initial peaks was undertaken. Because the peaks in a given test series may be expected to differ somewhat, the values of ten peaks were averaged for each test and the corresponding means and standard deviations were calculated.

Figure 4 presents the mean values (and the values of the means plus or minus one standard deviation) of the accelerations corresponding to the peaks observed with all four accelerometers on Cane No. 17, when it was tapped on the six test surfaces by the two users studied. Figure 5 presents similar information for Cane No. 3. The results of tapping relatively hard surfaces are shown on the left sides of these figures, whereas those corresponding to soft surfaces appear on the right sides; not surprisingly, the soft surfaces may be noted generally to be associated with lesser accelerations.

From the data presented in these two figures one is lead to conclude that the peak accelerations obtained with a given cane impacting a given surface often differ little for the two users, but that in many instances great differences occur between the accelerations observed for the two different canes tapped by the same person against the same surface. In other words, cane-to-cane differences appear to be more significant than user-to-user differences.

### 2.4.2 Peak Accelerations; Proportionality of Handle and Tip Magnitudes

Figures 6 and 7 are logarithmic plots of the peak acceleration values observed at the cane tip versus those observed at the handle. Both users and all six surfaces are represented, but the latter are not identified in these figures.

One may note that the data points for each tip accelerometer direction tend to cluster along straight lines with unity slope, such as those indicated in the figures. This trend implies that the handle acceleration is essentially proportional to the tip acceleration. One may expect changes in the tip acceleration magnitude--i.e., in the strength of the cane tapping impact--to change only the magnitude, but not the character, of the acceleration at the handle; therefore, the impact strength at which impact test are carried out is not likely to affect the character of the results.

From Figures 6 and 7 one further finds that the constants characterizing the aforementioned proportionalities are different for the two different canes, but that these constants are the same for different users with the same cane. As before, cane-to-cane differences are more pronounced than user-to-user differences, encouraging one to expect that useful cane characterization may be feasible without accounting for user differences.

### 2.4.3 Acceleration Spectra Compared to Threshold of Perception

Figures 8 through 11 present narrow band (1.25 Hz bandwidth) spectra of handle vibrations for the two canes and two users; each figure pertains to one cane in the hands of one user,

tapping against each of the six test surfaces. Each spectrum corresponds to the average of 16 impacts, so that the effects of random variations may be expected to be relatively small.

Also shown in each figure is a curve that corresponds to the approximate fingertip threshold of perception of vibration, obtained by interpreting Figure 71 of Geldard* in terms of acceleration. (This curve falls a few [at most, five] decibels lower than values derived from later work reported by Verrillo, et al.)** It may be noted that most of the data curves exceed the threshold curve by considerable margins in a number of frequency bands below 250 Hz. No such exceedance was observed above 250 Hz, indicating that above this frequency no vibrotactile information is conveyed by the canes. For the sake of clarity, the portions of the data curves that fell below the threshold were discarded in the course of preparation of Figures 8 to 11 from the original data records.

From Figures 8 through 11 one may thus draw the clear conclusion that cane tapping results in handle vibrations that can be felt, and that these perceptible vibrations are confined to frequencies below about 250 Hz. No conclusions may be drawn, however, concerning whether and how cane users make use of this vibrotactile information.

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* Frank A. Geldard, The Human Senses, John Wiley & Sons, Inc., New York, 1953., p187

** Ronald T. Verrillo, 'Effect of Contactor Area on the Vibrotactile Threshold,' JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA, 35(12), 1962-66; 1963; Ronald T. Verrillo, Anthony J. Fraioli, and Robert L. Smith, 'Sensation Magnitude of Vibrotactile Stimuli,' PERCEPTION & PSYCHOPHYSICS, 6 (6A), 366-371; 1969; Ronald T. Verrillo, 'Vibrotactile Sensitivity and the Frequency Response of the Pacinian Corpuscle,' PSYCHON. SCI., 4, 135-6; 1966.

By comparing Figures 8 through 11 with each other, one once again finds that cane-to-cane differences tend to be greater than user-to-user differences.

### 2.4.4 Sound Spectra Compared to Threshold of Hearing

The data acquired outdoors could not be analyzed meaningfully because the background noise (which was typical of noise in a sparsely populated urban area with light traffic) masked the sound produced by the canes. Similarly, the sound produced by the canes on carpet indoors proved to be so low that it could not be extracted from the background noise. For the cane user who wore hard-heeled shoes, the data analysis could not distinguish between cane and heel impacts.

Thus, the only useful data obtained was that for the user with soft heels walking indoors on hard surfaces. This data is summarized in Figure 12, which presents narrow band (25 Hz bandwidth) spectra of the A-weighted* sound pressure levels corresponding to the average of 32 tapping impacts.

Comparison of the cane tapping sound spectra of Figure 12 with the threshold of hearing, which is also indicated in that figure, indicates that the cane tapping sounds are markedly above the hearing threshold at all frequencies below about 9000 Hz (even though these sounds often may be below the background noise). Some differences between the spectra obtained with the two canes are also evident, particularly in the 0 - 2 KHz and 5 - 8 KHz regions; one may note that the spectra for the same

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* "A-weighting" refers to standardized frequency-dependent corrections added to sound spectra in order to relate these spectra more directly to how the sound is perceived. E.g., see A.P.G. Peterson and E.E. Gross, Jr., HANDBOOK OF NOISE MEASUREMENTS, General Radio Corp., Concord, Mass., 1972

cane tapping against different surfaces also differ most pronouncedly in these frequency regions.

## 2.5 An Approach to Cane Evaluation

### 2.5.1 Rationale

Since the magnitudes (or absolute levels) of vibration or sound spectra associated with tapping depend on the strengths of the tapping impacts, and the tapping strengths depend more on the user than on the cane, it appears logical not to consider these magnitudes in the process of comparing or evaluating canes.

It is well known that people can discriminate between sounds that have different spectrum shapes associated with them, whereas sounds with like spectrum shapes, but different magnitudes, sound alike (but have different loudness). Since one of the purposes of a cane may be to aid in discrimination between different surfaces, it seems appropriate to compare canes in terms of the variations in the shapes of the spectra of the sounds that are produced when the canes are tapped against different surfaces. In other words, a cane for which there occur large differences in the spectrum shapes for various surfaces is likely to be better for discrimination between these surfaces than is a cane for which there occur lesser spectrum shape differences.

Much less appears to be known about how people discriminate between vibrotactile stimuli than about how they discriminate between audible sounds. It seems appropriate, however, to assume that the concepts discussed in the foregoing paragraph in relation to sound also apply to vibrotactile stimuli.

### 2.5.2 Normalized Spectra

Figures 13 and 14 show the cane vibration spectra of Figures 8 to 11, but shifted vertically so as to make the lowest-frequency peaks of all spectra coincide with that corresponding to tapping on asphalt. (The choice of the asphalt spectrum as the one to which the others are matched is purely arbitrary; selection of another condition would result merely in shifting all normalized spectra up or down together.) The magnitude of the low-frequency peak is related to the tapping impact strength; thus, making these peaks match amounts to normalizing the spectra to the same impact strength.

It is evident from figures 13 and 14 that for both users the spectra for cane No. 3 differ much more from each other than those for No. 17, leading one to conclude that cane No. 3 provides more information for vibrotactile discrimination than does Cane No. 17. It is also of interest to note that the spectra for different users tend to overlap considerably, if these spectra are normalized so as to make the low-frequency peaks match.

Figure 15 shows the cane sound spectra of Figure 12, but with the spectra corresponding to cement shifted vertically to make their portions in the 1 to 5 KHz region match as nearly as possible the spectra corresponding to tapping on tile. The region for which matching was done was selected because the greatest spectrum similarities were found there; it has no other particular significance. Although the situation is by no means very clear, it appears that the spectra for Cane No. 3 differ a little more from each other (primarily in the 6 to 8 KHz range) than do those for Cane No. 17, implying that cane No. 3 may be slightly better for auditory discrimination between the two surfaces considered.

# 3. LABORATORY MEASUREMENTS

## 3.1 Exploratory Experiments

A series of experiments were undertaken with the intent of arriving at simple, repeatable tests that provide the desired differentiation between canes under conditions that approximate those encountered in use. The concept of the pendulum suggested itself immediately for the purpose of obtaining controlled impacts, in view of the well-known fact that the velocity that a pendulum has at the bottom of its swing depends only on the height from which it is released (as measured from its bottom position), and not on the weight or length of the pendulum. Furthermore, a relatively long string supporting a cane may be expected to affect the cane's vibrations only negligibly, and thus not to distort its vibration characteristics.

Initial exploratory measurements were made on the same canes (Nos. 3 and 17) that were employed in the in-use tests. Each cane was fitted with accelerometers as in the in-use tests and was hung from two 5-foot long strings so that its axis was horizontal. A concrete block (covered with various materials, such as carpeting or wood blocks, as needed) was placed so that the cane tip would hit the surface of the block just as the pendulum formed by the string-supported cane passed through its bottom-most position. Several swing and impact directions were tried. First, the canes were pulled away from their pendulum equilibrium positions essentially in their axial directions and their tips were made to impact perpendicularly against the test surfaces. Then the canes were pulled aside laterally and various concrete block surface orientations relative to the cane tip were explored. It turned out that lateral impacts gave less repeatable results than axial impacts, because of the associated

rotations that the canes tended to execute in the horizontal plane. It was also found that axial impacts perpendicular to the test surfaces gave vibration results that rank-ordered the two canes differently than did the in-use tests.

The simplest repeatable test that correlated well with the in-use results was found to be one involving axial motion of the cane, but with the impacted surface oriented at 45 degrees to the cane axis. A five-foot pendulum length proved convenient, and releasing the cane from a location that is 14 inches (horizontally) from the equilibrium position was found to yield conveniently measurable vibrations.

In several of the previously described experiments, accelerometers were mounted on the rubber grips, as well as next to these grips. Because the signals from the on-grip accelerometers were found not to differ significantly from those provided by the corresponding off-grip accelerometers, only accelerometers mounted next to the rubber grips (where attachment could be accomplished more reliably) were used in the subsequent measurements.

In an attempt to simulate the vibration-restraining effect of a hand gripping the cane, a number of measurements were carried out with an "artificial hand" attached to the rubber grip. This device consisted of a 1/2-inch thick layer of fiberglass wrapped around the rubber grip, with a 1/4-inch thickness of leaded vinyl wrapped tightly around the fiberglass in the middle 5 inches of the grip length. The fiberglass was intended to model the compressibility of the flesh of the hand, and the leaded vinyl, the mass of the hand. However, this artificial hand was found to introduce more problems than it was worth (i.e., it made the results less repeatable and introduced

vibrations of its own that masked those of the cane), so that it was discarded for subsequent tests.

A number of vibration measurements were made with hand-held canes to explore the effects of how strongly the canes were gripped. These measurements were made with a person tapping a cane against a cement surface, and also with a person sliding the cane tip along that surface. It was found for both conditions that the hand generally produced only minor changes in the shapes of the cane vibration spectra, but that their magnitude decreased as the cane was gripped more tightly. These results again indicate that cane comparisons can be made most readily in absence of any real or simulated hand.

## 3.2 Standardized Tests

### 3.2.1 Overview

As the result of the previously described exploratory experiments, two tests were selected and standardized for the vibratory and acoustical characterization of canes:

(1) Pendulum impacts of the cane against test surfaces oriented at 45 degrees to the cane axis.

(2) Sliding of cane tip against test surfaces.

In both tests, both vibration and sound measurements were made with three test surfaces: cement, wood and carpet. However, no sound data were taken for the carpet, because this data is both unreliable and of no practical significance.

### 3.2.2 Impact Tests

The arrangement employed for impact tests is shown in Figure 16. The cane to be characterized was suspended from the ceiling of a semi-anechoic room by means of two 5-foot long strings. Near its rubber grip, an accelerometer was attached to the cane with its sensing axis perpendicular to the cane axis and at a 45 degree angle from the vertical. A microphone was placed 18 inches behind, 12 inches above, and 6 inches to the right of the end of the handle (as seen from the point of view of a person holding the cane by its handle).

An impact block, consisting of a 4-inch thick 1-foot square cement panel, was set up (on any convenient support, such as a chair) so that its front surface made a 45-degree angle with the cane axis and so that its midpoint nearly touched the tip of the cane when the cane hung in its equilibrium position. For impacts against wood, a smooth 1-foot long 2" x 4" block was taped to the front of the impact block (and that block was moved away from the cane) so that the center of the wood block then nearly touched the cane tip when the cane hung freely. For impacts against carpet, a carpet sample was placed across the face of the impact block; the carpet was held tightly against the block's surface by means of tape and rubber bands.

For each test impact, the cane was pulled back 14 inches (essentially along its axis, in the horizontal direction) and then released. A short (about 6-inch) length of string attached at the back of the cane handle, or the fabric or elastic band with which many canes are furnished, was found convenient for pulling back the cane with minimal misalignment.

Each test run consisted of 16 impacts of the same cane against the same surface. The signals generated by these impacts were averaged and subjected to automatic spectrum analysis by

means of the instrumentation indicated in Figure 17. In order to not to increase the instrumentation requirements, it was found convenient to make different test runs for the vibration and for the noise data, and to feed signals either from the accelerometer or from the microphone to the data acquisition instrumentation.

### 3.2.3 Sliding Tests

The sliding tests basically involved placing the previously described test surfaces flat on the floor of a semi-anechoic chamber and having a person slide the tip of the cane being tested across the test surface. The cane was held in a realistic attitude, at about 45 degrees with the plane of the floor, and all sliding was done by pushing the cane forward, roughly in the direction of its axis. In order to minimize the effect of the experimenter's hand, the cane in these tests was held (and pushed) by means of two 8-inch lengths of string tied to the end of the handle, with the experimenter holding one with his left hand and one with his right hand.

The same accelerometer attachment locations near the front edge of the rubber grip (or a similar location for canes that had no grip) were used here as for the impact tests. However, for the sliding tests, the accelerometer axis was kept in the vertical plane (in order to measure in the direction of the greatest motion, in which direction the effect of the hand-held support strings also is least). In the present tests, a microphone was placed in the approximate position of a user's ear--about 2 feet behind the end of the handle, as measured horizontally, and about 5 feet above the floor.

Each test run consisted of sliding a given cane 16 times against a given test surface (in the forward direction only). The resulting signals were averaged and analyzed by means of the

instrumentation shown in Figure 17; as for the impact tests, different runs were made to acquire vibration data and noise data.

## 3.3 Results

### 3.3.1 Data Presentation

The data obtained for all of the canes tested are presented in the 24 pages of graphs included at the end of this report. In order to facilitate comparison, a standardized format is used that shows all of the salient data for a given cane on a single page.

### 3.3.2 Cane Comparisons

As discussed in section 2.5.1 of this report, a cane for which there occur large differences in the shapes of the spectra associated with auditory or vibrotactile stimuli resulting from the cane's tapping or sliding against different surfaces is likely to be better for discrimination between these surfaces than a cane for which there occur smaller differences in the spectrum shapes. One may thus obtain a convenient estimate of a tested cane's capability to aid in discrimination by noting the differences in the shapes of the spectra presented in its "Cane Vibration and Sound Characterization" chart at the end of this report.

In the summary table that appears at the end of this report, discrimination ratings have been assigned to each cane tested. One such rating is indicated for each of the four standard measurements: vibration due to impact (simulating tapping), vibration due to sliding, sound due to impact, and sound due to sliding. The sums of the vibrotactile ratings, of the auditory

ratings, and of the two ratings together (giving an overall rating) are also indicated in the table, together with information that characterizes the canes in more general terms.

The discrimination ratings have been derived on the basis of simple visual comparisons of the spectra pertaining to the concrete and wood test surfaces.* Where the spectra differ little, a rating of 0 has been assigned; where great spectrum shape differences occur, a rating of 2 has been indicated; intermediate cases have been assigned a rating of 1. Thus, higher ratings correspond to greater differentiation capability.

From the summary table, it appears that the canes that are best from the vibrotactile discrimination viewpoint are number 5, if it is provided with a steel tip, and number 10, which came with a steel tip. Although number 5 is made of aluminum and number 10 of steel, both have low bending stiffness. Because "softer" structures tend to vibrate more readily in concert with specific excitations than structures with greater stiffness, it appears logical that more flexible structures should provide greater potential for vibrotactile discrimination. Significantly, all but one of the six test canes with vibrotactile ratings of 0 were judged to have high or medium bending stiffness.

The canes with the highest sound discrimination rating are number 5, when fitted with a steel tip, and numbers 17 and 19, which came with steel tips. The latter two canes, unlike number 5, have high bending stiffnesses and are nonfolding. Number 5

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* Differentiation between these two hard and rather similar surfaces clearly is more difficult than differention between either one of these and relatively soft carpet. For this reason, the spectra pertaining to carpet have not been considered in this simple preliminary rating scheme.

and number 17 are made of aluminum tube, whereas number 19 is of wood. Rods of these materials typically produce more sound when they are scraped or tapped than do hollow or solid rods of reinforced plastic.

One may note that the cane tip has a major effect on the discrimination potential provided by a cane, in terms both of vibrotactile and auditory stimuli. Cane number 5, which has the highest total rating when it is fitted with a steel tip, becomes one of the three lowest rated canes when it is fitted with a nylon tip. Cane number 1, which also was tested with both types of tips, also rates higher with a steel tip than with a nylon tip. Of the seven test canes with a total rating of 1 or 2, five had nylon tips.

## 4. Conclusion

A series of relatively simple tests has been devised for rating the capabilities of canes to provide auditory and vibrotactile information that cane users may employ to differentiate between surfaces with which the canes make contact.

On the basis of such tests of 22 different canes, of which two canes were tested with different tips, it was found that canes with steel tips generally provide considerably more auditory and vibrotactile information than do canes with nylon tips. Canes with relatively low bending stiffness appeared to be better from the vibrotactile viewpoint than stiffer canes, and canes of acoustically "live" materials and configurations (which generate sound readily when scraped or tapped) were found to be better from the auditory information viewpoint than canes of "dead" materials.

Of the various canes tested, a steel-tipped folding cane made of aluminum tubing and weighing 9-1/2 ounces turned out to have the highest total discrimination potential rating.

It is important to note, however, that the tests discussed in this report only evaluate a cane's capability for providing vibrotactual and auditory information to a cane user. The extent to which cane users actually employ this information, how they do this, and which stimulus type they find more useful are questions that remain to be resolved.

## CANE TEST RESULTS

| Sample Number | Tip Material[1] | Cane Material[1] | Bending Stiffness[2] | Handle[3] | Grip[4] | Folding[5] | Length, Folded (in.) | Weight (oz) | Discrimination Rating[6] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Vibration | | | Sound | | | |
| | | | | | | | | | Tapping | Sliding | Total | Tapping | Sliding | Total | Total |
| 1 | NY | AL | M | S | PL | F | 10 | 8 | 0 | 1 | 1 | 0 | 1 | 1 | 2 |
| 1 | ST | AL | M | S | PL | F | 10 | 8 | 1 | 1 | 2 | 0 | 2 | 2 | 4 |
| 2 | NY | AL | M | S | ME | F | 9 | 11 | 1 | 1 | 2 | 2 | 1 | 3 | 5 |
| 3 | NY | AL | M | S | RU | F | 14 | 8½ | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| 4 | ST | ST | L | S | PL | T | 10 | 8¾ | 1 | 0 | 1 | 1 | 1 | 2 | 3 |
| 5 | ST | AL | L | S | RU | F | 14 | 9½ | 2 | 1 | 3 | 2 | 2 | 4 | 7 |
| 5 | NY | AL | L | S | RU | F | 14 | 9½ | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 6 | ST | AL | L | S | RU | F | 14 | 8 | 1 | 0 | 1 | 1 | 1 | 2 | 3 |
| 7 | ST | AL | H | C | N | T | 23 | 10 | 0 | 0 | 0 | 1 | 1 | 2 | 2 |
| 8 | ST | AL | H | S | PL | T | 21 | 12 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 9 | NY | ST | M | S | RU | F | 13 | 10 | 1 | 1 | 2 | 2 | 0 | 2 | 4 |
| 10 | ST | RP | L | S | N | T | 11 | 3 | 1 | 2 | 3 | 1 | 1 | 2 | 5 |
| 11 | NY | ST | M | C | RU | N | - | 8½ | 0 | 0 | 0 | 2 | 1 | 3 | 3 |
| 12 | NY | RP | L | S | RU | N | - | 5 | 0 | 1 | 1 | 0 | 1 | 1 | 2 |
| 13 | NY | AL | M | C | RU | N | - | 8½ | 1 | 0 | 1 | 1 | 1 | 2 | 3 |
| 14 | ST | AL | M | C | RU | N | - | 9 | 1 | 0 | 1 | 1 | 1 | 2 | 3 |
| 15 | NY | RP | L | C | RU | N | - | 5½ | 1 | 1 | 2 | 1 | 1 | 2 | 4 |
| 16 | NY | AL | M | C | RU | N | - | 10 | 1 | 0 | 1 | 1 | 1 | 2 | 3 |
| 17 | ST | AL | H | S | RU | N | - | 8½ | 0 | 0 | 0 | 2 | 2 | 4 | 4 |
| 18 | NY | AL | M | C | RU | N | - | 8½ | 0 | 1 | 1 | 2 | 0 | 2 | 3 |
| 19 | ST | WD | H | C | N | N | - | 8 | 1 | 0 | 1 | 2 | 2 | 4 | 5 |
| 20 | ST | RP | L | S | PL | N | - | 9 | 0 | 0 | 0 | 1 | 2 | 3 | 3 |
| 21 | NY | AL | M | C | RU | N | - | 9 | 1 | 1 | 2 | 1 | 1 | 2 | 4 |
| 22 | NY | RP | M | S | RU | N | - | 8 | 0 | 0 | 0 | 1 | 1 | 2 | 2 |

[1] AL = Aluminum
NY = Nylon
RP = Reinforced Plastic
ST = Steel
WD = Wood

[2] H = High (rigid)
M = Medium
L = Low (flexible

[3] C = C-shaped
S = Straight

[4] RU = Rubber (soft)
PL = Plastic (hard)
ME = Metal
N = None

[5] F = Folding
T = Telescoping
N = Non-folding

[6] 0 = Little Difference*
1 = Some Difference
2 = Marked Difference

---

*Between wood and concrete.

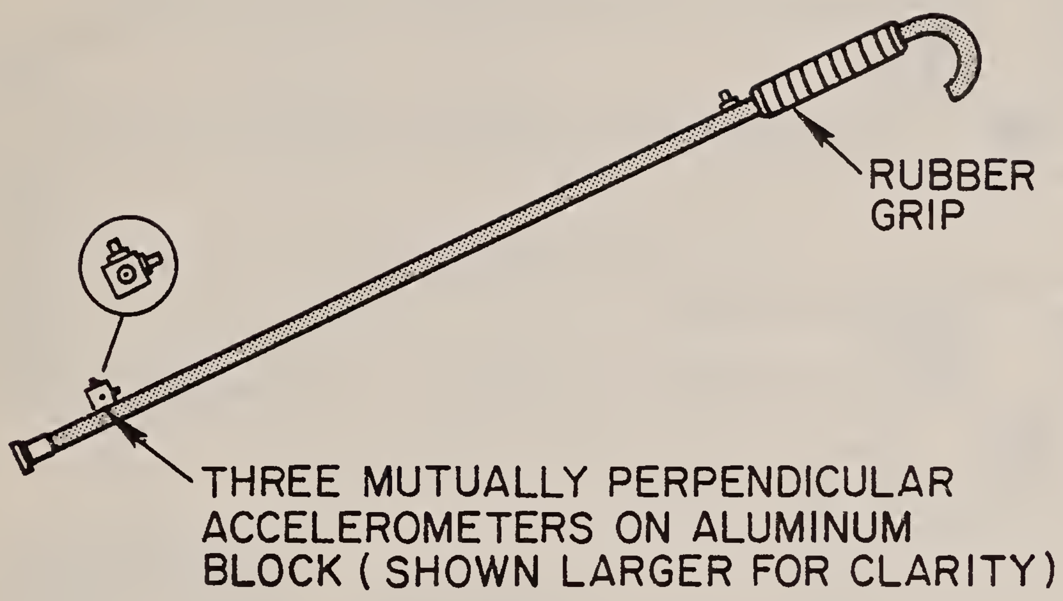

RUBBER GRIP
THREE MUTUALLY PERPENDICULAR ACCELEROMETERS ON ALUMINUM BLOCK ( SHOWN LARGER FOR CLARITY)

Figure 1. Accelerometer Locations on Use Test Canes

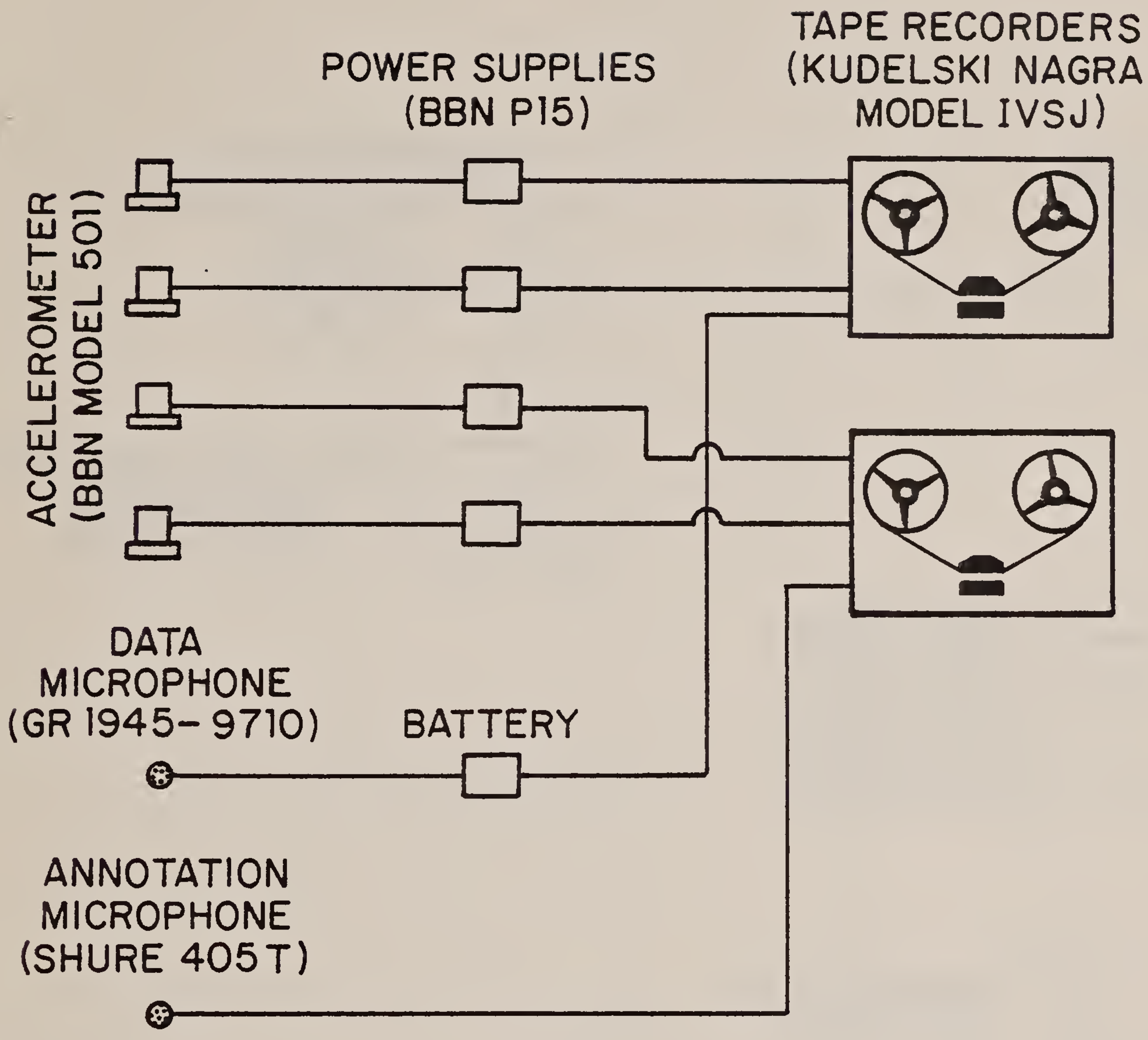

TAPE RECORDERS
(KUDELSKI NAGRA
MODEL IVSJ)
POWER SUPPLIES
(BBN P15)
ACCELEROMETER
(BBN MODEL 501)
DATA
MICROPHONE
(GR 1945-9710)
BATTERY
ANNOTATION
MICROPHONE
(SHURE 405T)

Figure 2. Data Acquisition System for Use Tests

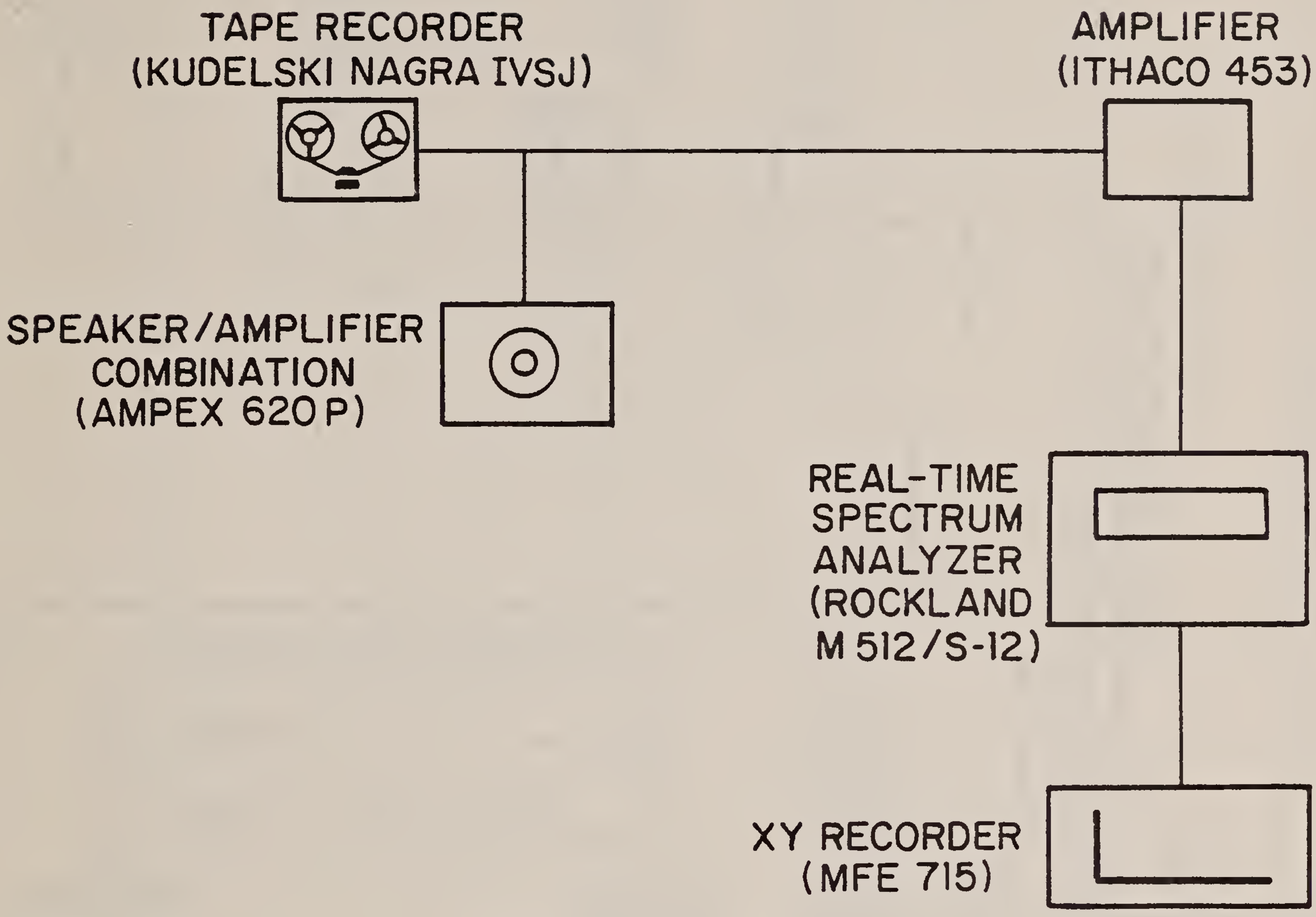

TAPE RECORDER
(KUDELSKI NAGRA IVSJ)
AMPLIFIER
(ITHACO 453)
SPEAKER/AMPLIFIER
COMBINATION
(AMPEX 620 P)
REAL-TIME
SPECTRUM
ANALYZER
(ROCKLAND
M 512/S-12)
XY RECORDER
(MFE 715)

Figure 3. Data Reduction Instrumentation

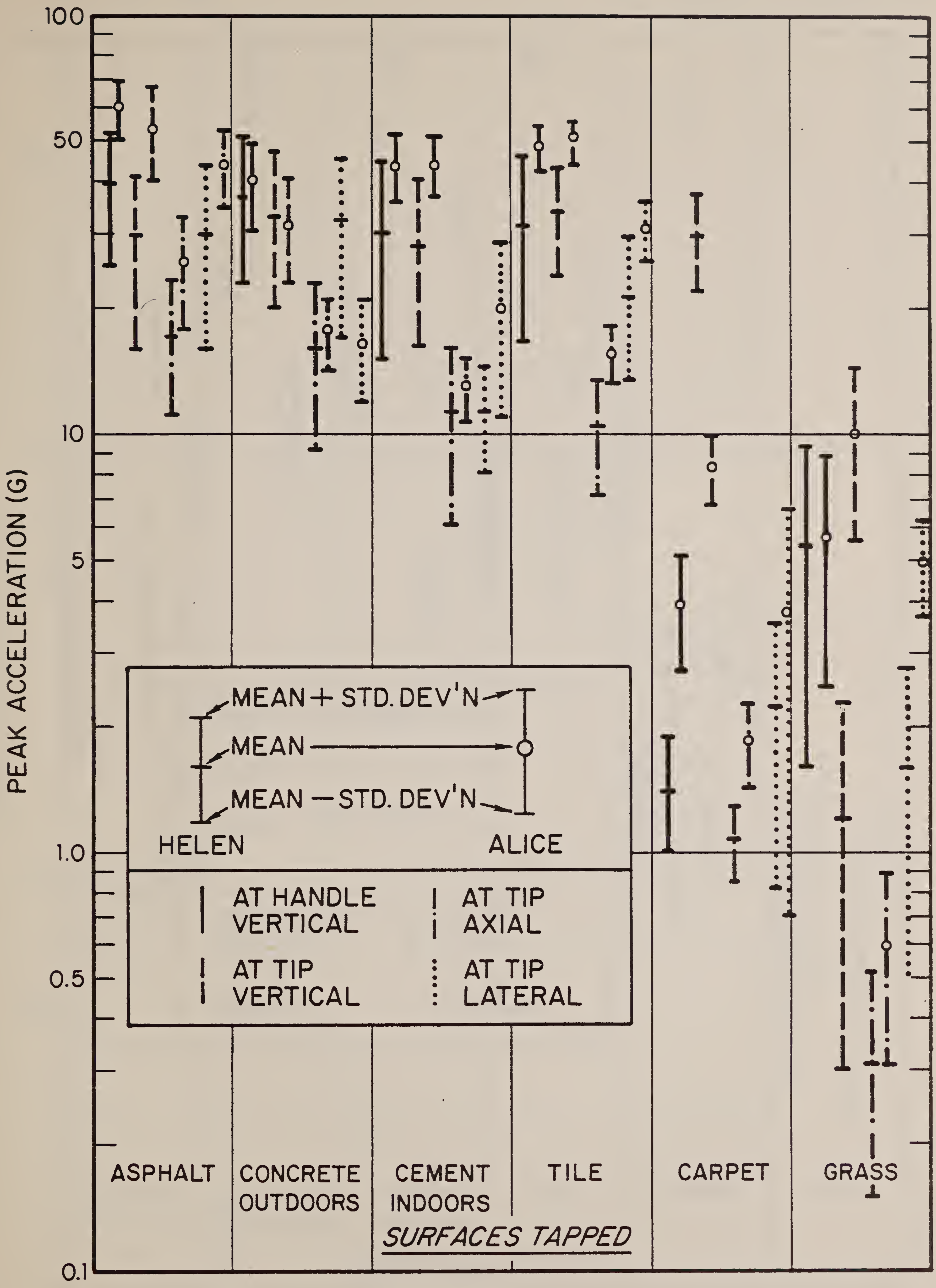


Figure 4. Peak Accelerations Observed in Use Tests of Cane No. 17

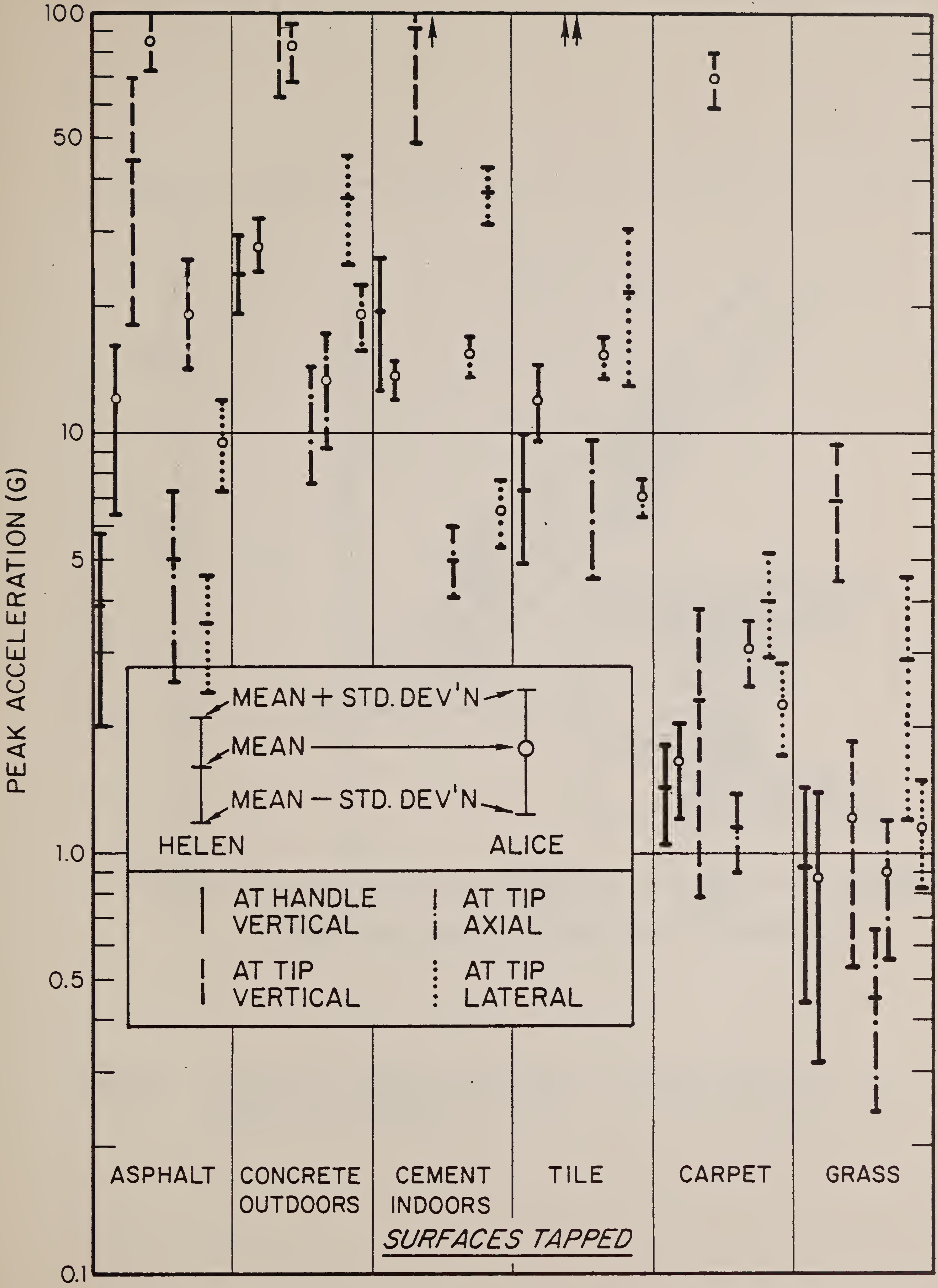


Figure 5. Peak Accelerations Observed in Use Tests of Cane No. 3

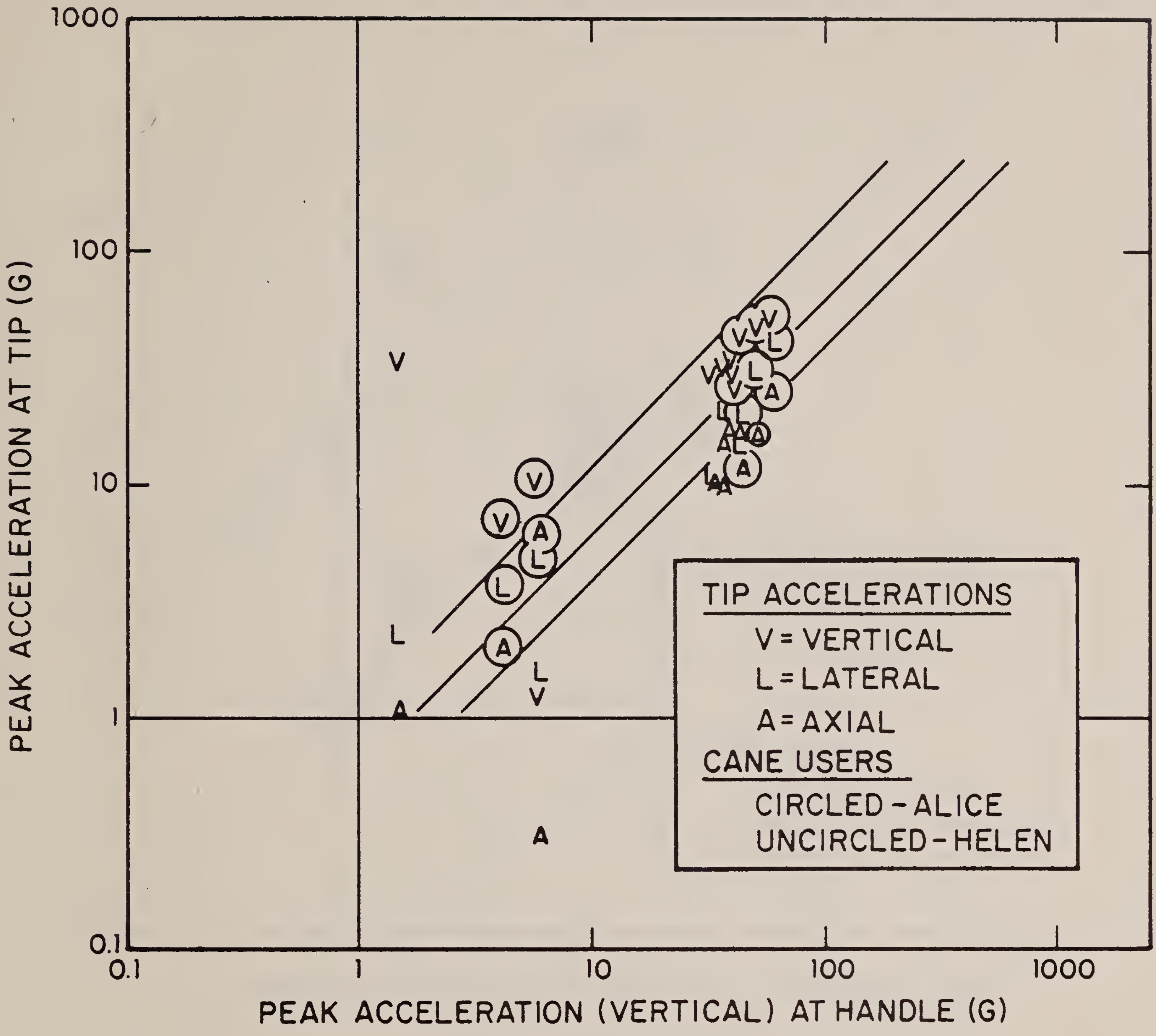


Figure 6. Variation of Peak Accelerations at the Tip with that at the Handle, for Cane No. 17

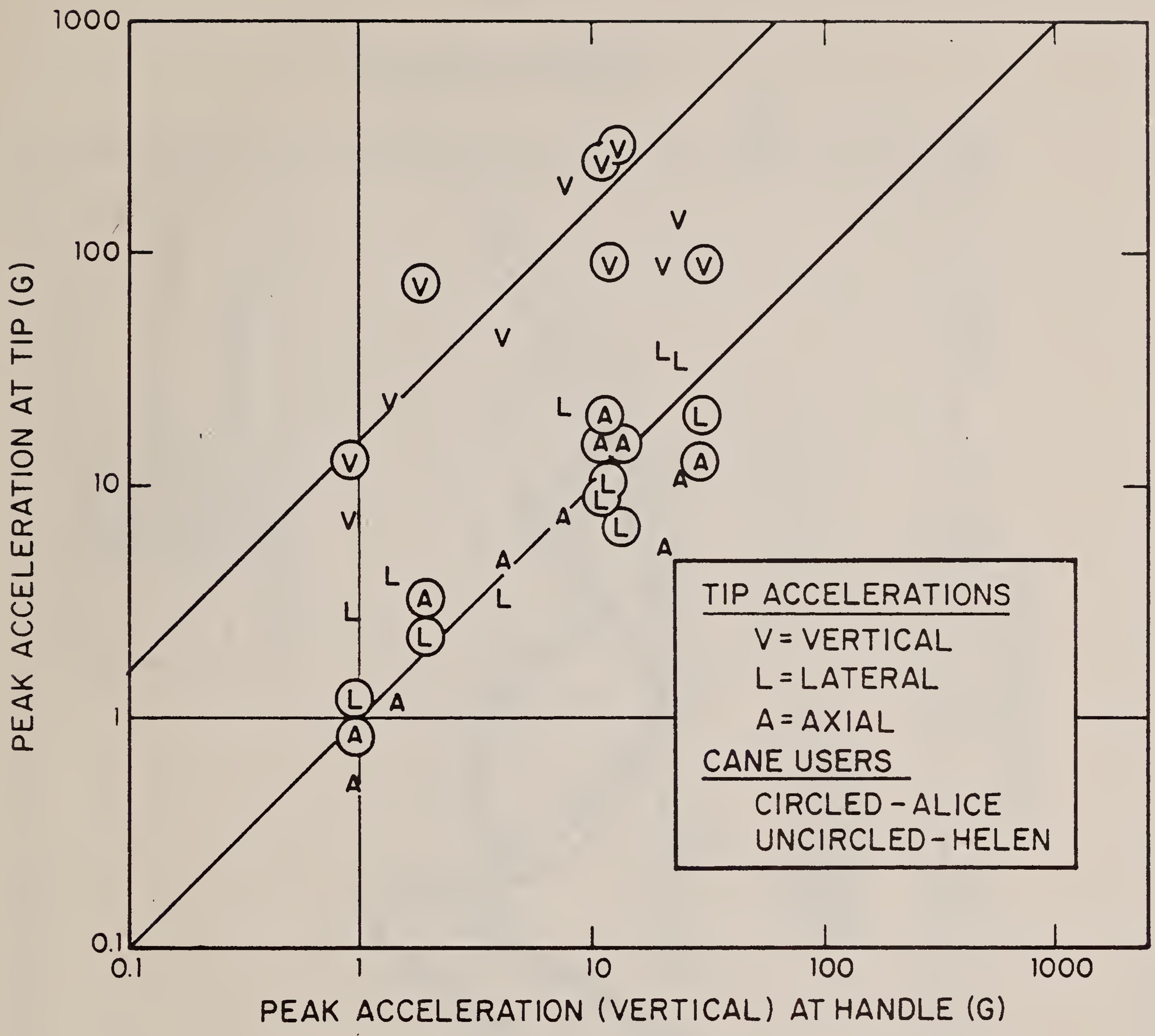


Figure 7. Variation of Peak Accelerations at the Tip with that at the Handle, for Cane No. 3

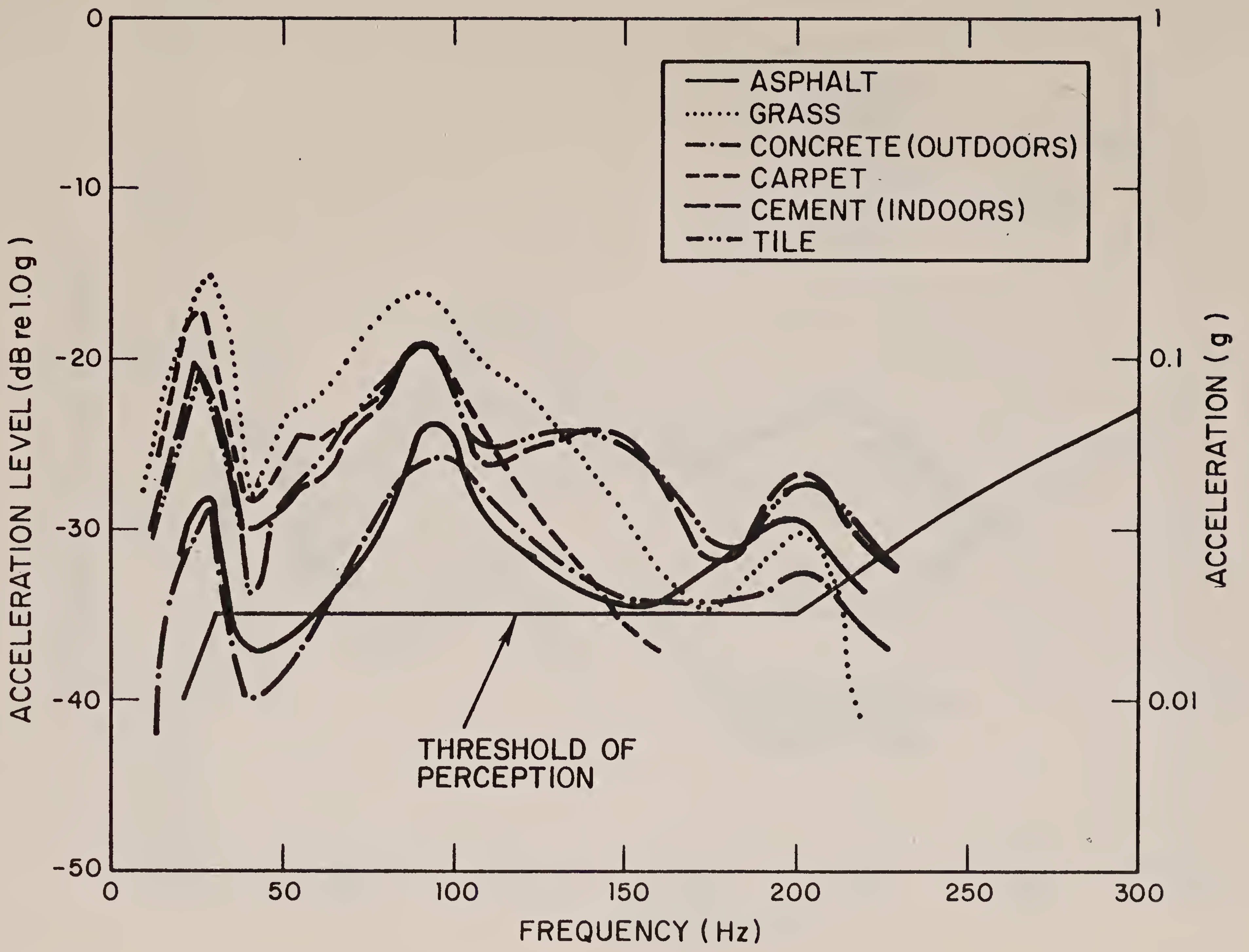


Figure 8. Handle Acceleration Spectra for Cane No. 17 Used by Alice

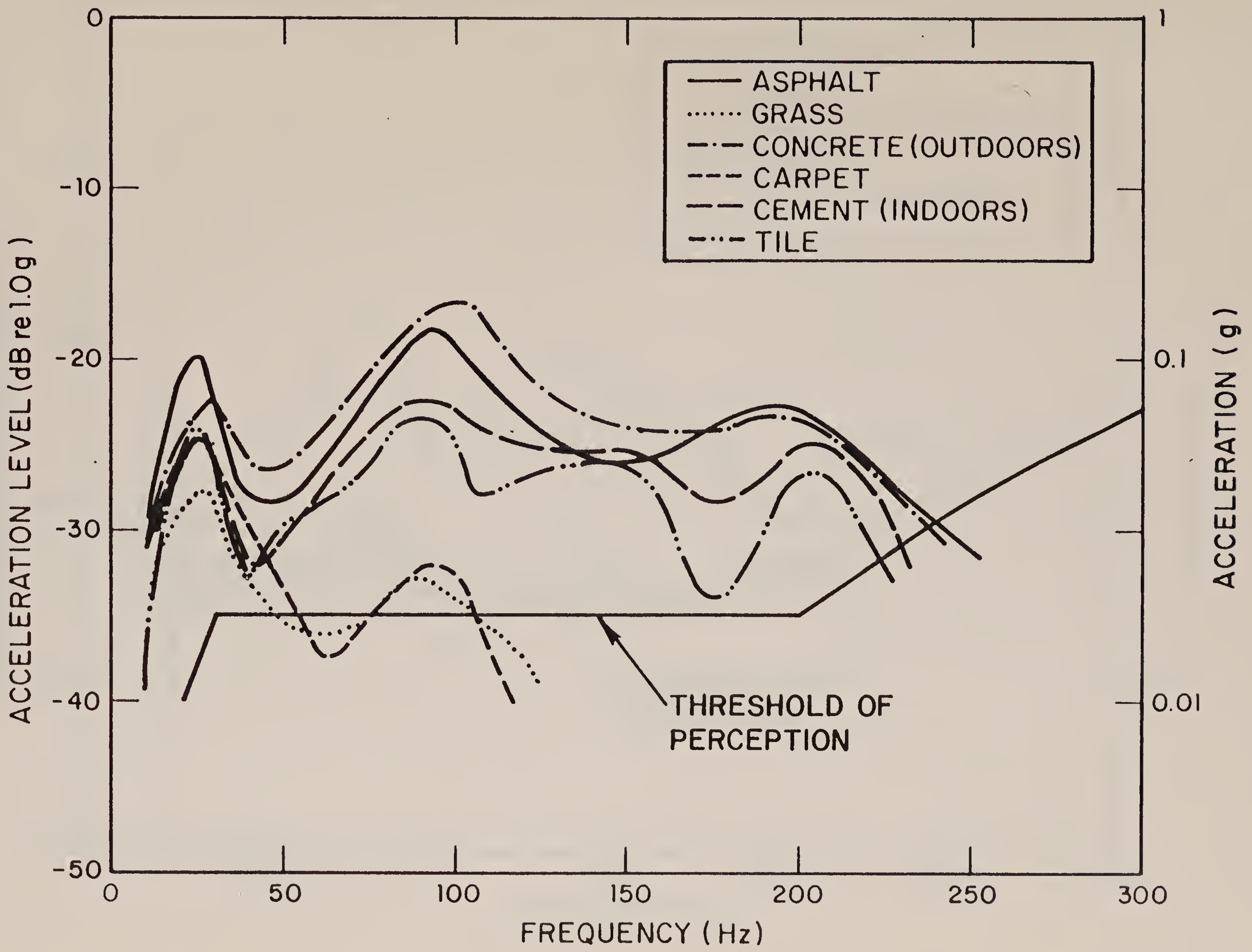


Figure 9. Handle Acceleration Spectra for Cane No. 17 Used by Helen

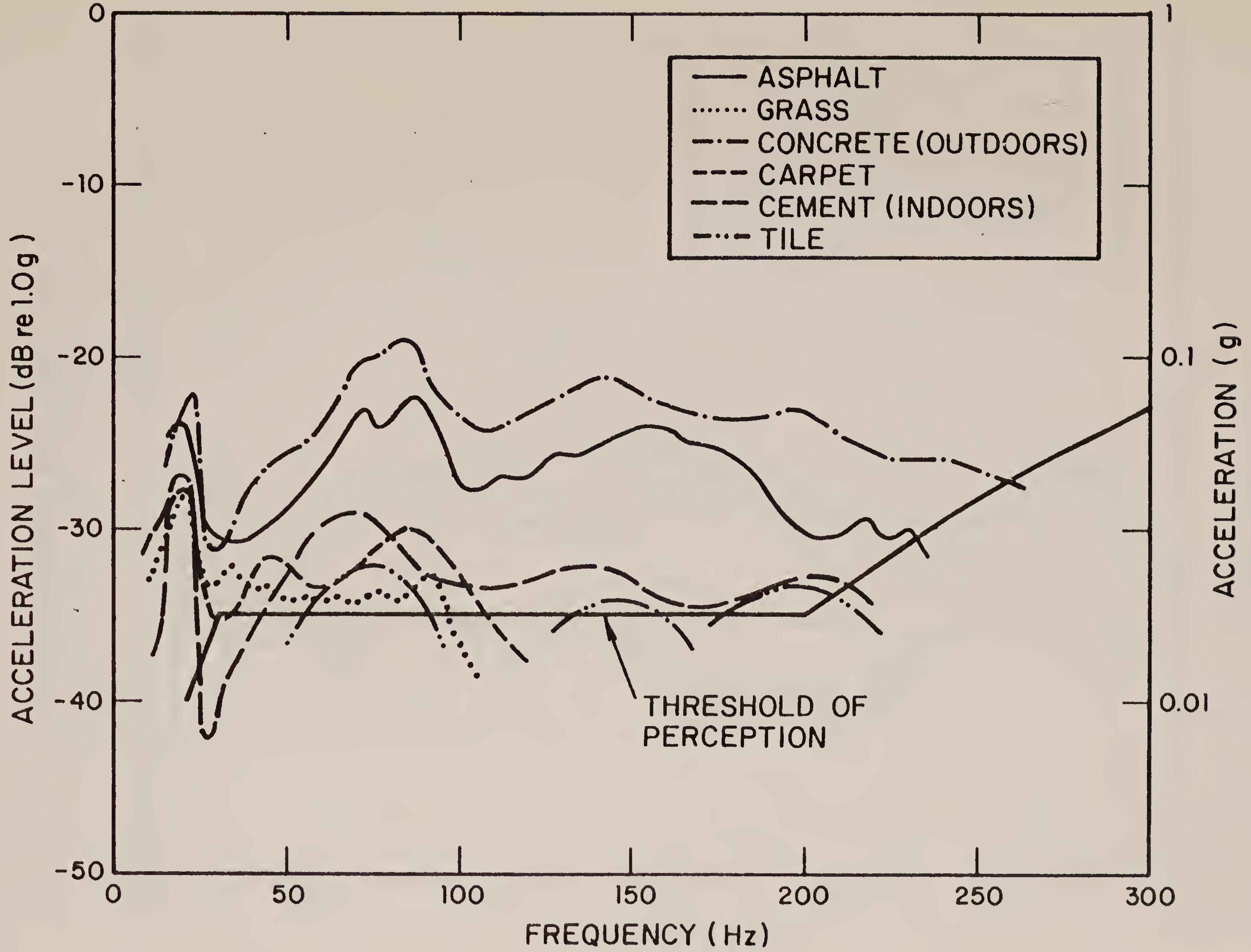


Figure 10. Handle Acceleration Spectra for Cane No. 3 Used by Alice

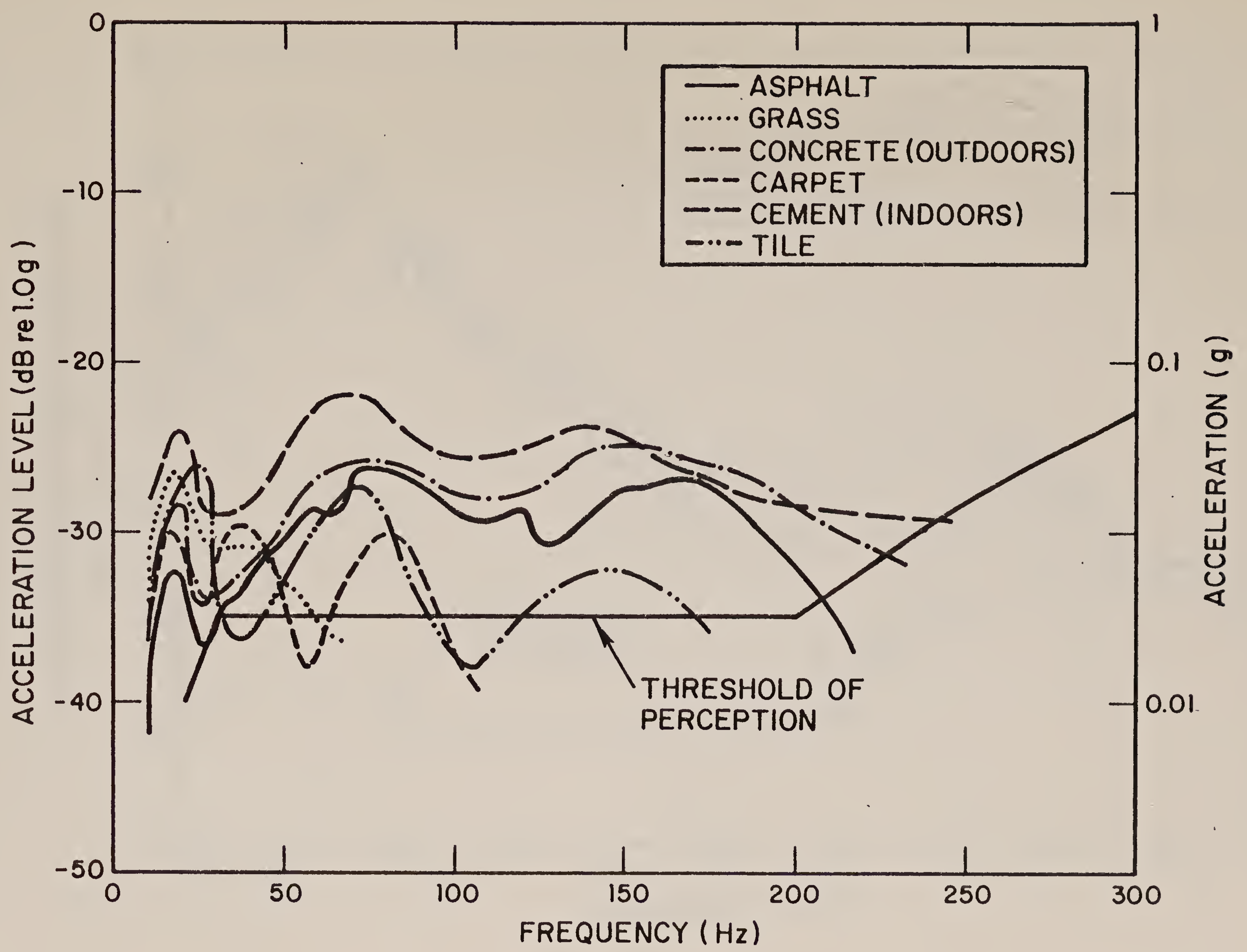


Figure 11. Handle Acceleration Spectra for Cane No. 3 Used by Helen

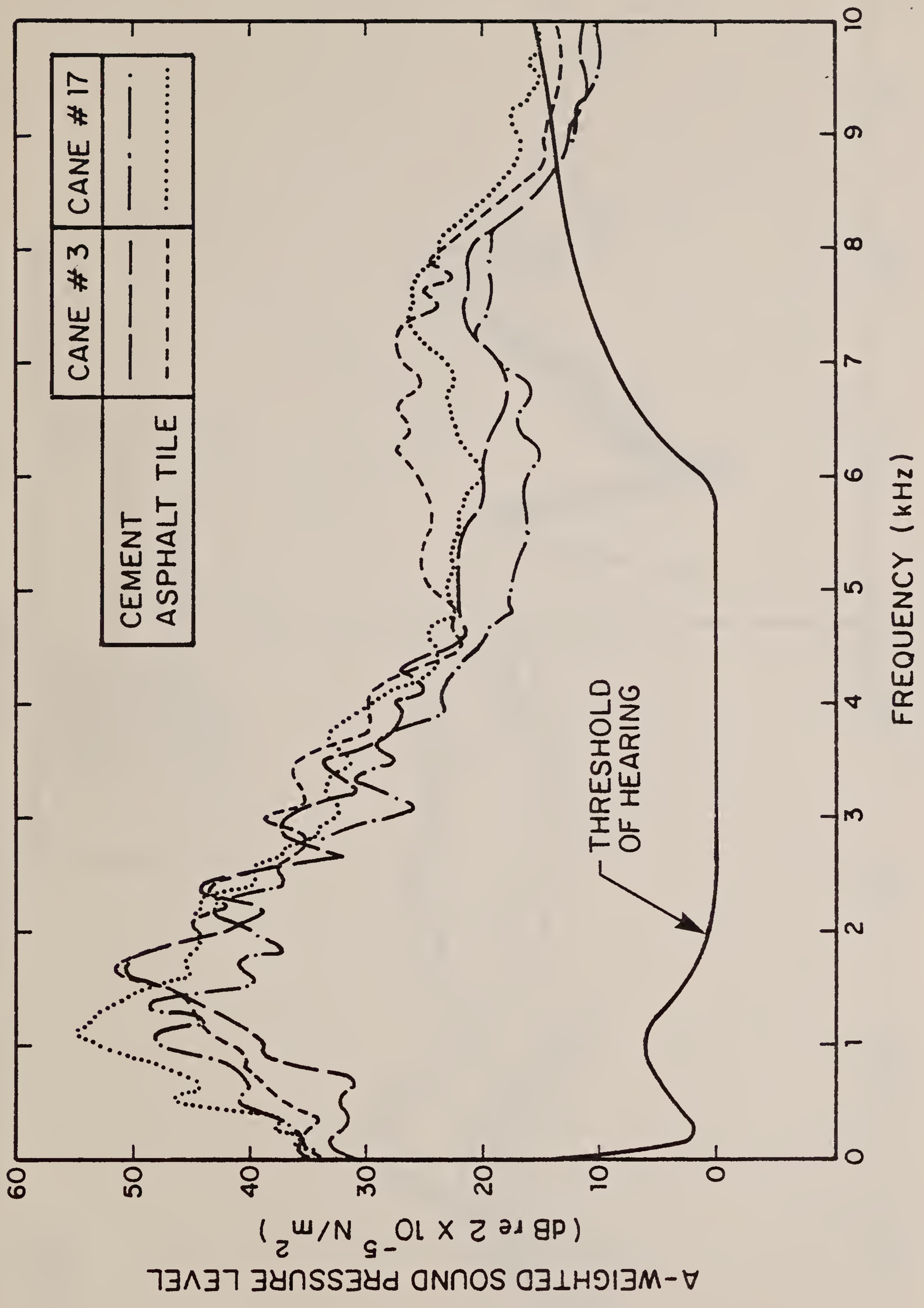


Figure 12. Spectra of Cane Tapping Sound at User's Ear

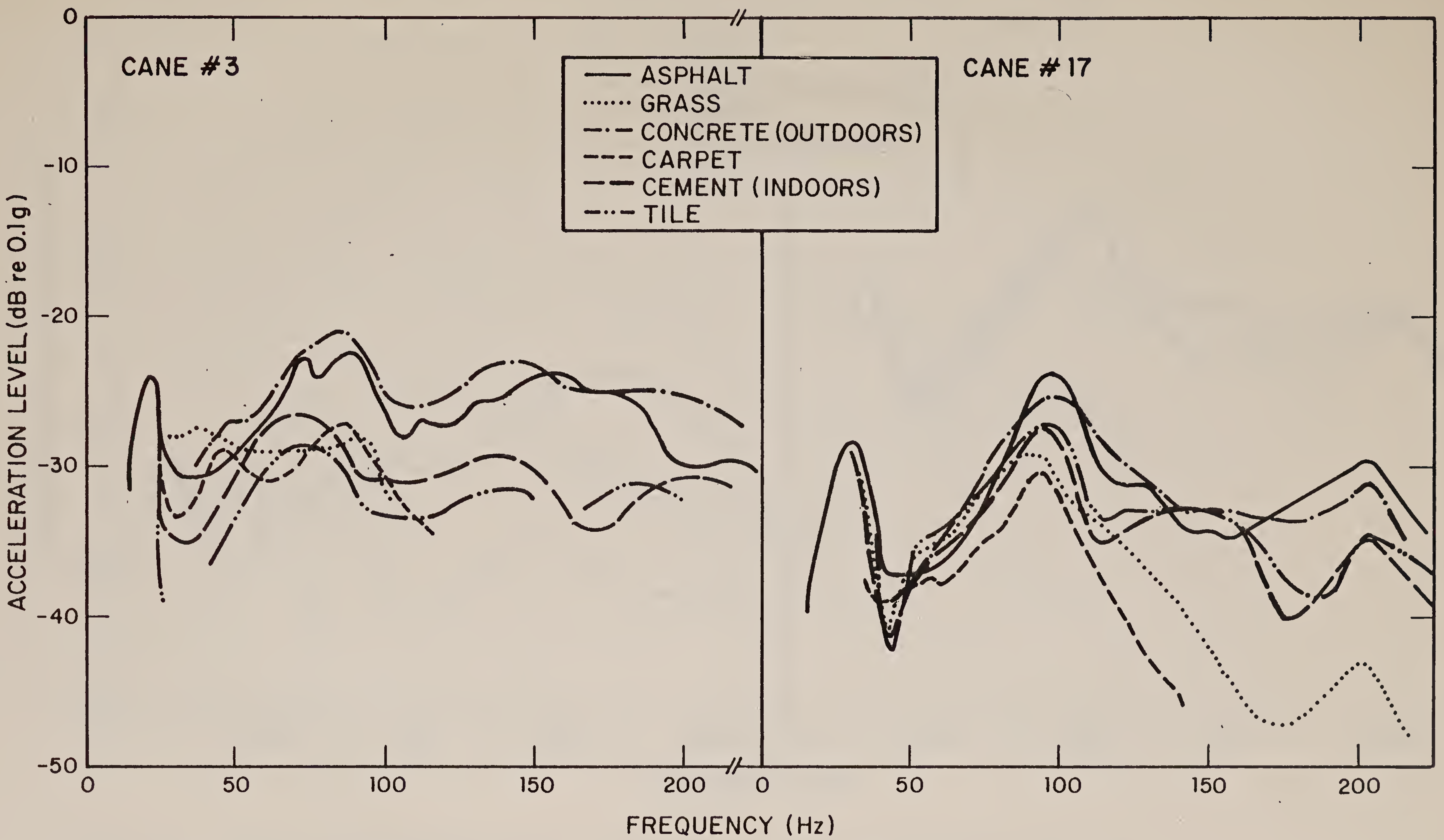


Figure 13. Handle Acceleration Spectra, Normalized to Low-frequency Peak on Asphalt. Cane Nos. 3 and 17, Used by Alice

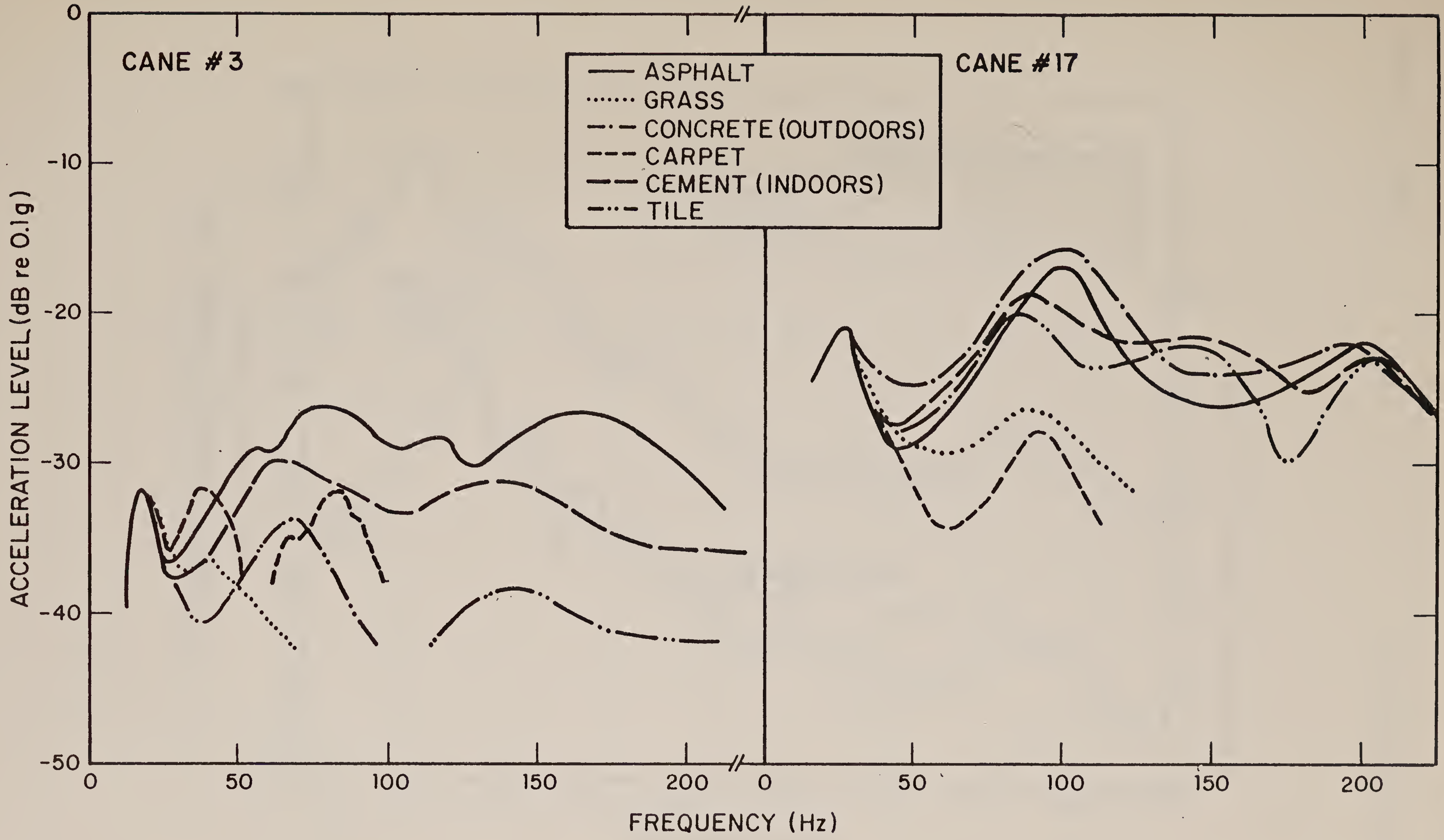


Figure 14. Handle Acceleration Spectra, Normalized to Low-frequency Peak on Asphalt. Cane Nos. 3 and 17 Used by Helen

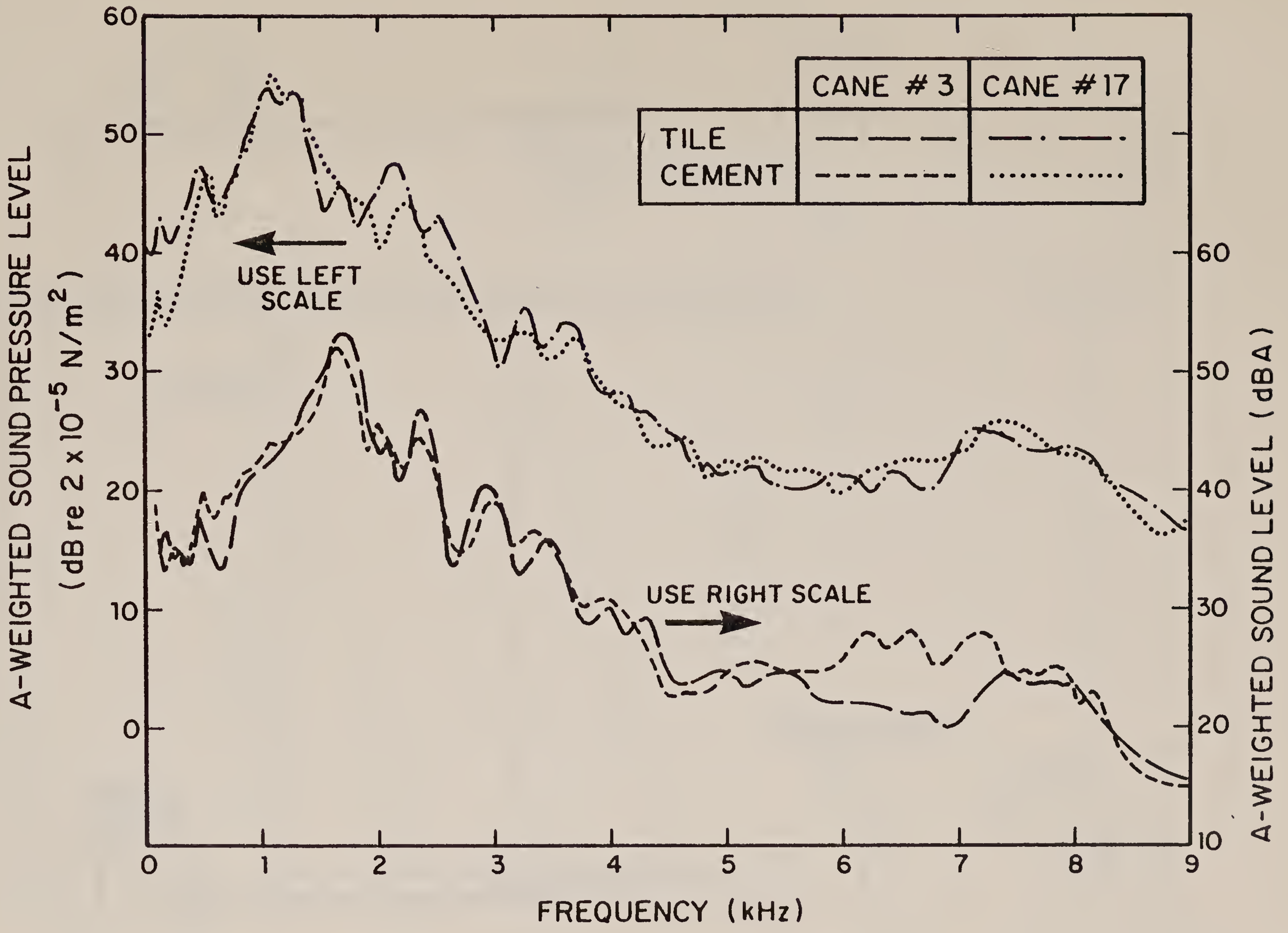


Figure 15. Sound Spectra Normalied to Mid-frequency Components on Tile. Cane Nos. 3 and 17, used by Alice.

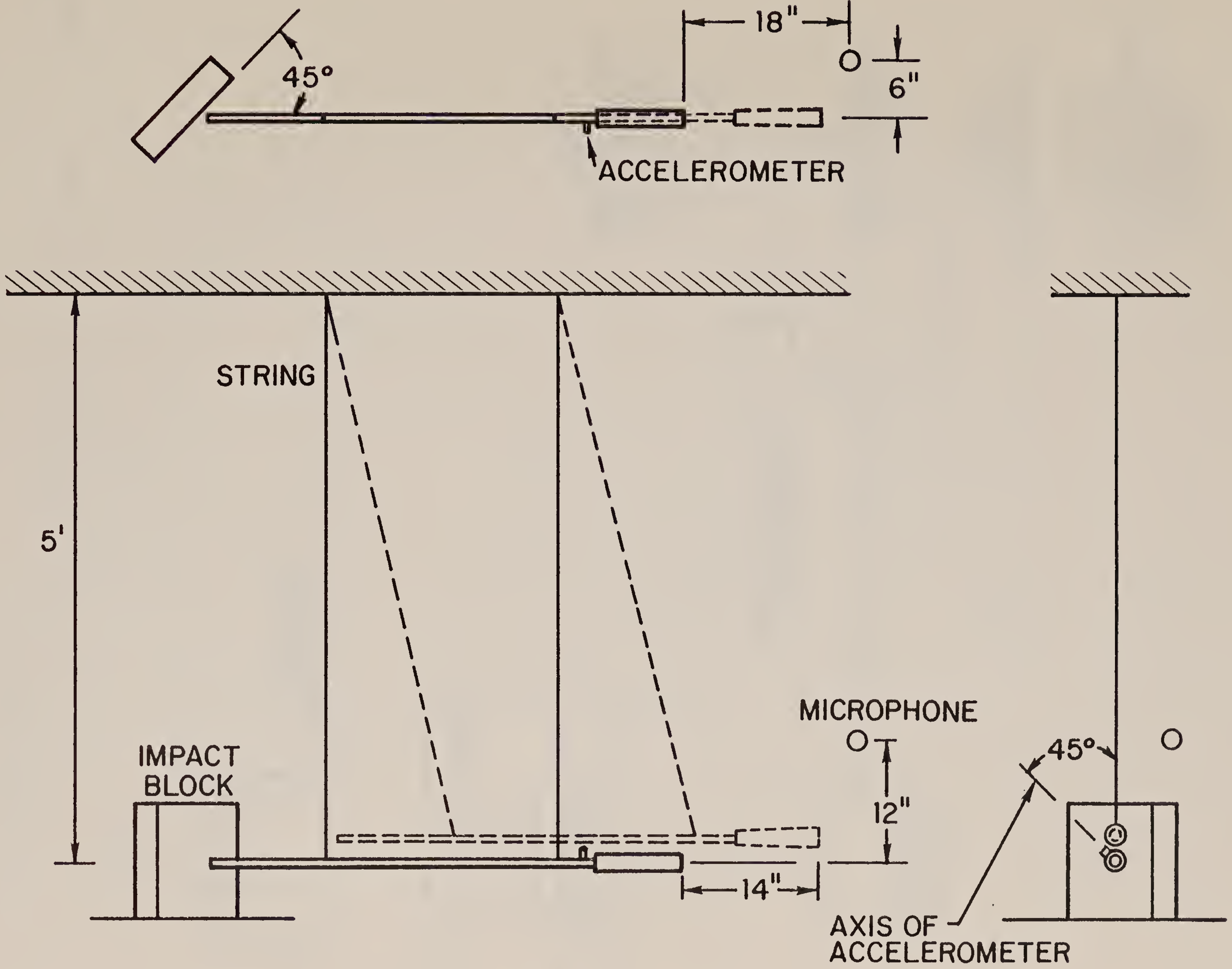

18"
45°
6"
ACCELEROMETER
STRING
5'
MICROPHONE
12"
14"
IMPACT BLOCK
45°
AXIS OF ACCELEROMETER

Figure 16. Three-view Sketch of Impact Arrangement (dotted figure shows cane deflected from equilibrium, ready for release).

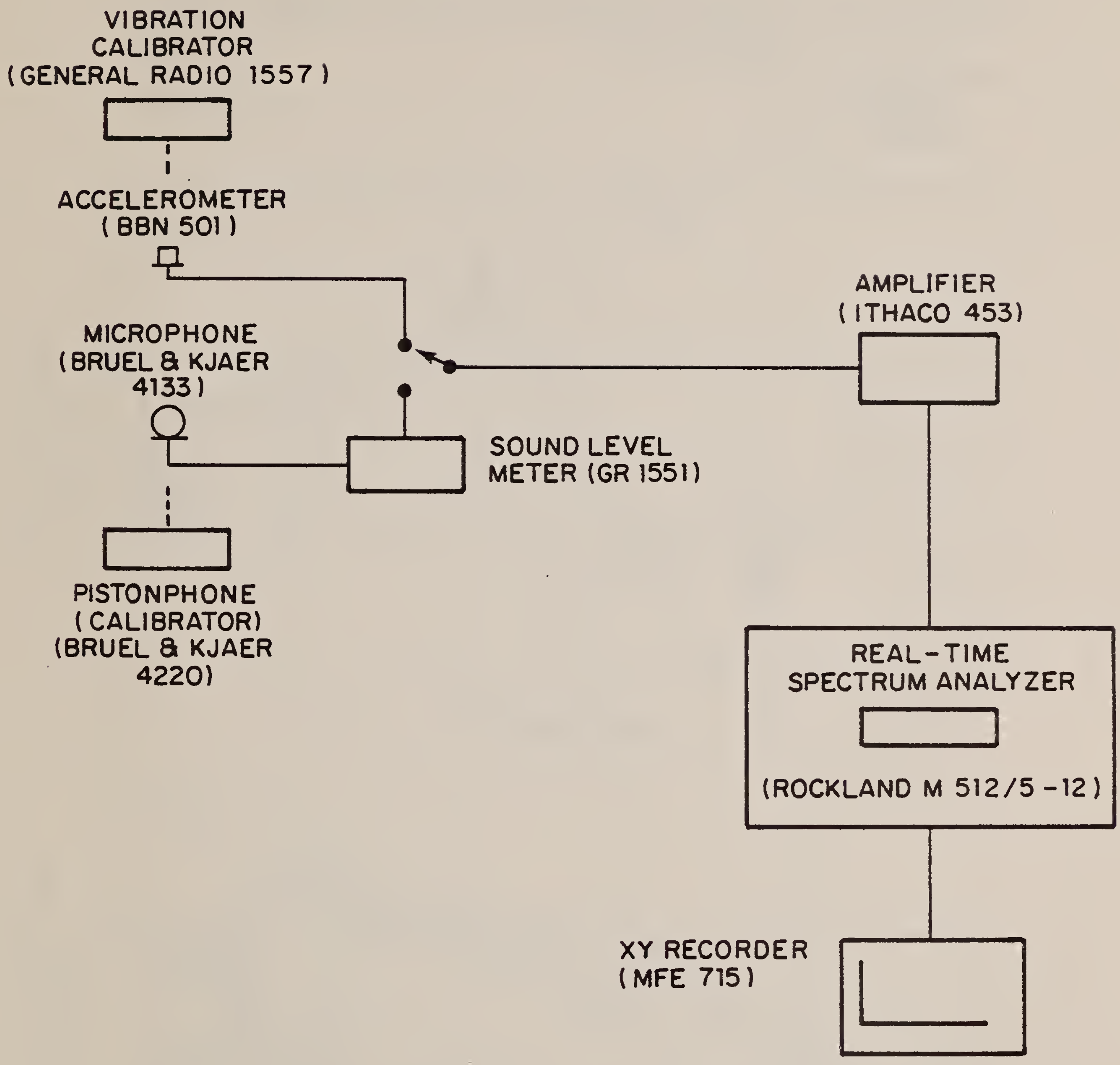
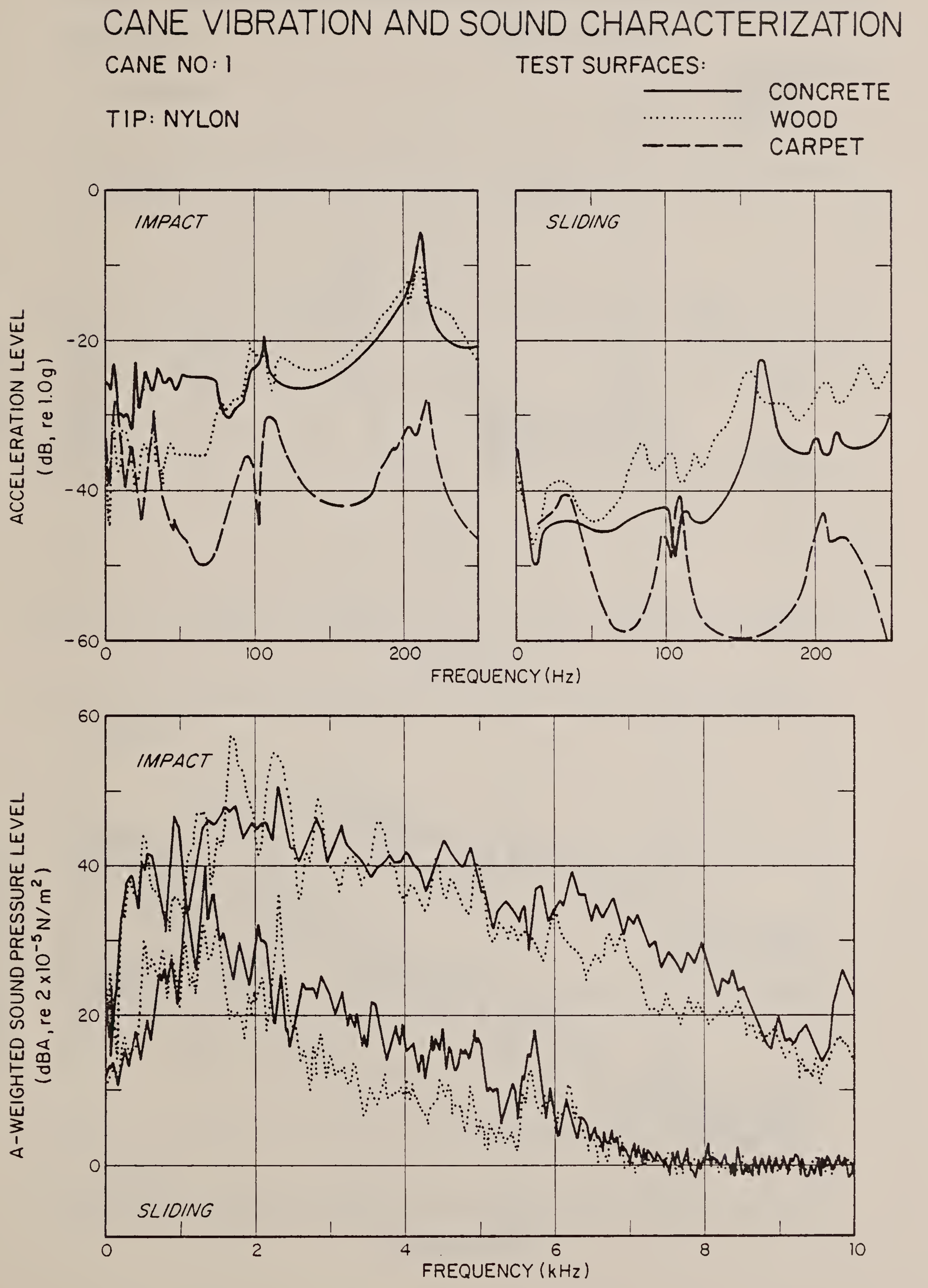
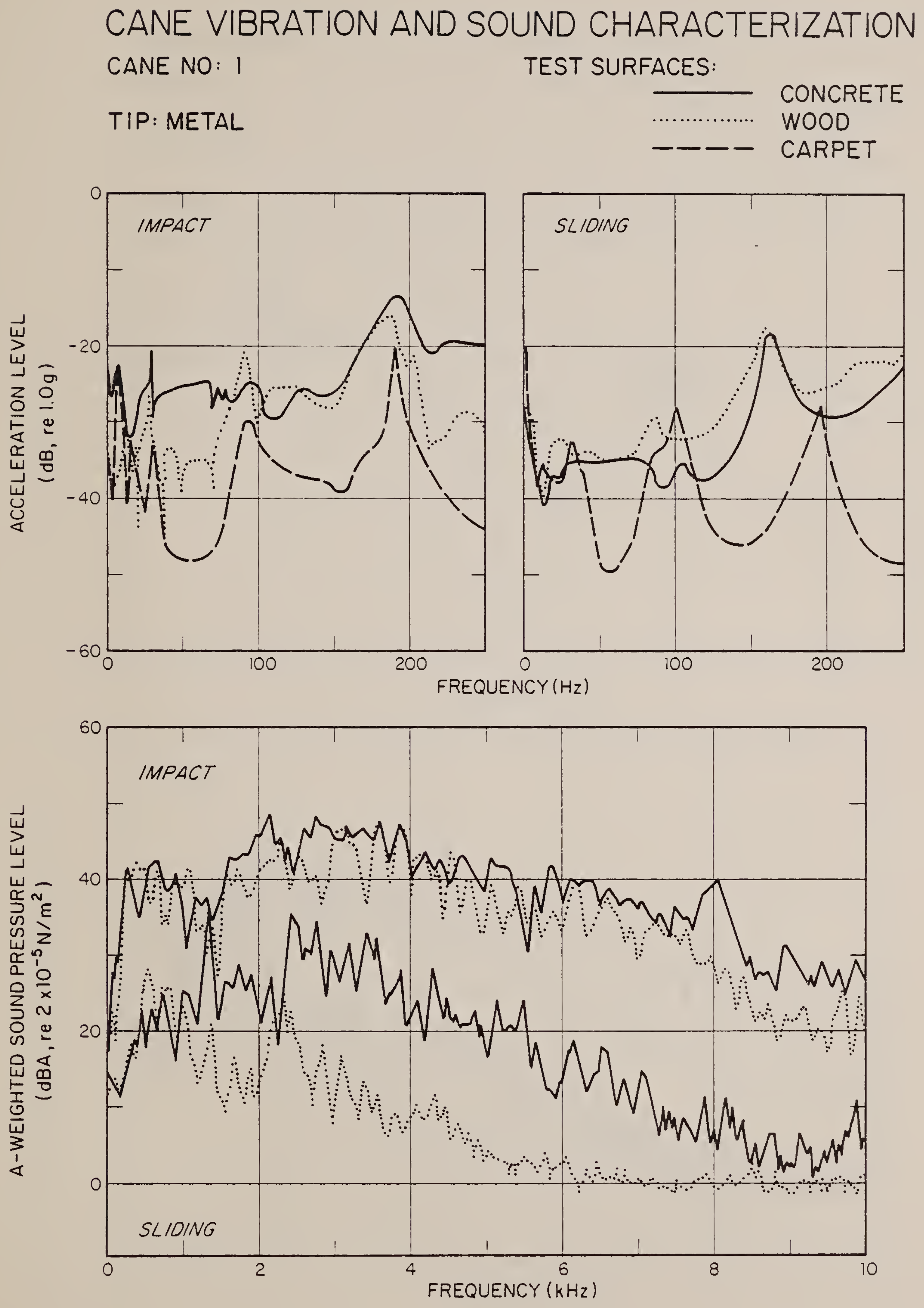
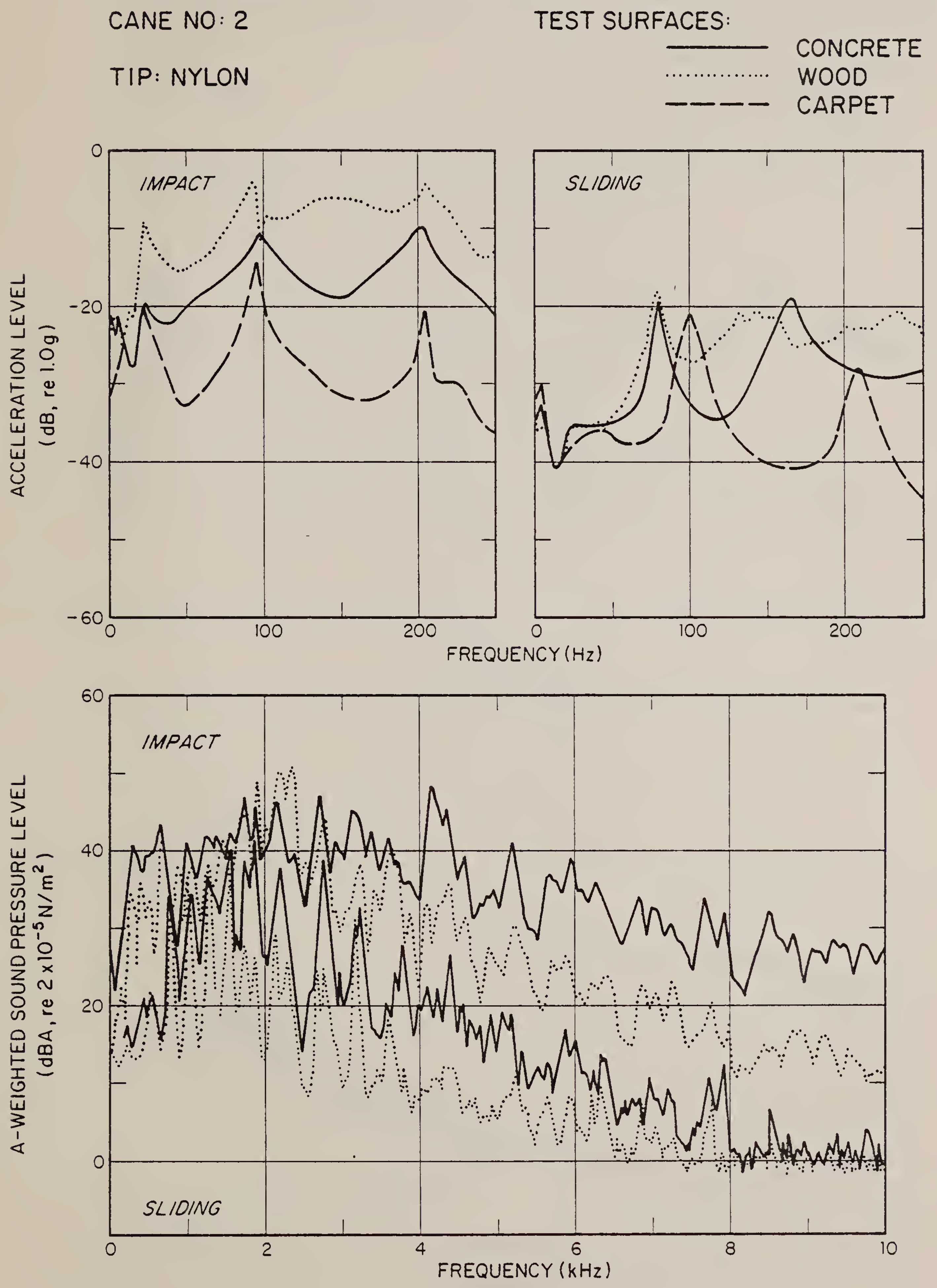

VIBRATION
CALIBRATOR
(GENERAL RADIO 1557)
ACCELEROMETER
(BBN 501)
MICROPHONE
(BRUEL & KJAER
4133)
PISTONPHONE
(CALIBRATOR)
(BRUEL & KJAER
4220)
SOUND LEVEL
METER (GR 1551)
AMPLIFIER
(ITHACO 453)
REAL-TIME
SPECTRUM ANALYZER
(ROCKLAND M 512/5-12)
XY RECORDER
(MFE 715)

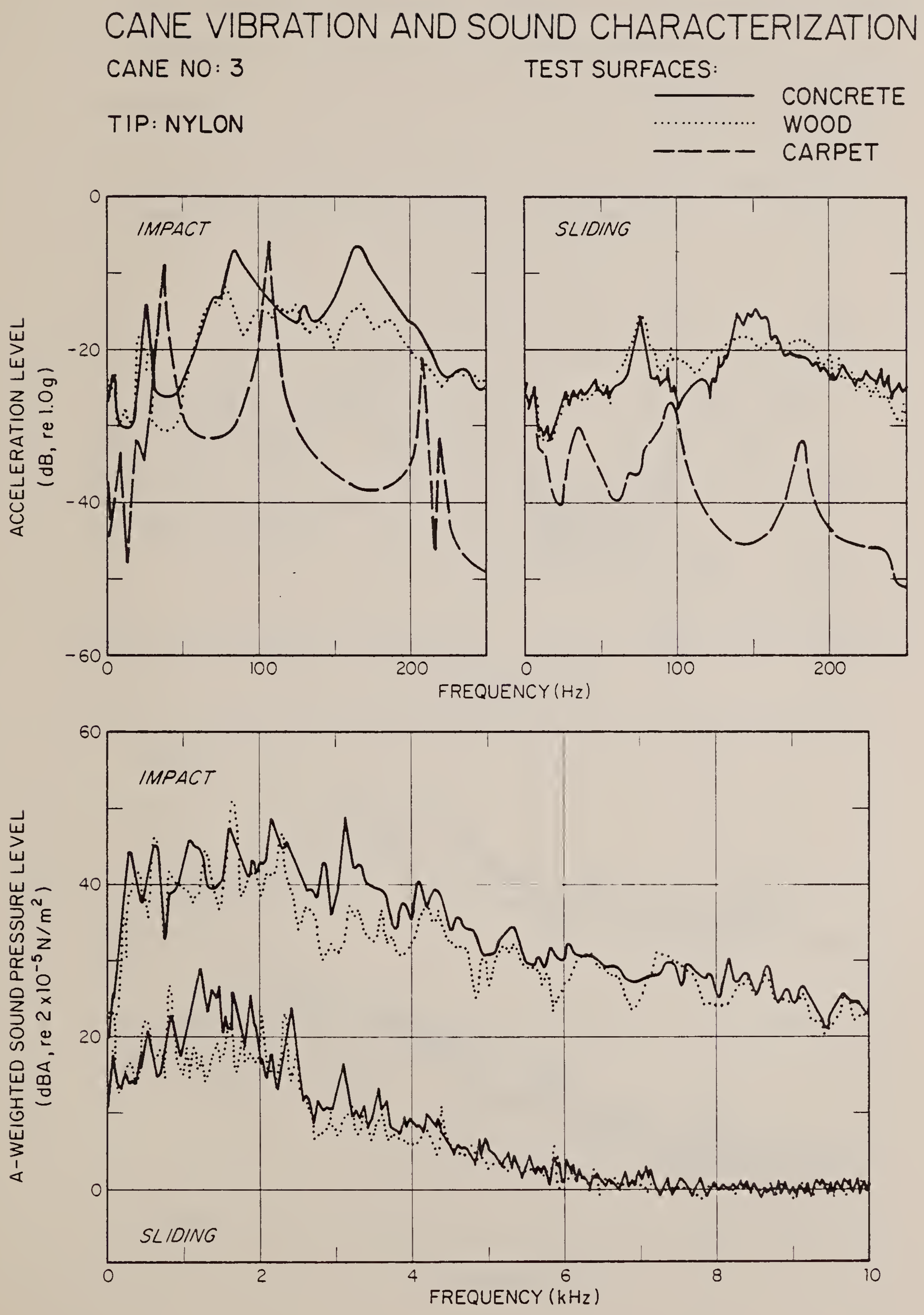
Figure 17. Data Acquisition Instrumentation


CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 1
TIP: NYLON
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
IMPACT
SLIDING
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x 10⁻⁵ N/m²)
60
40
20
0
2
4
6
8
10
FREQUENCY (kHz)


CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 1
TIP: METAL
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
IMPACT
SLIDING
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x 10^-5 N/m^2)
60
40
20
0
2
4
6
8
10
FREQUENCY (kHz)

CANE VIBRATION AND SOUND CHARACTERIZATION



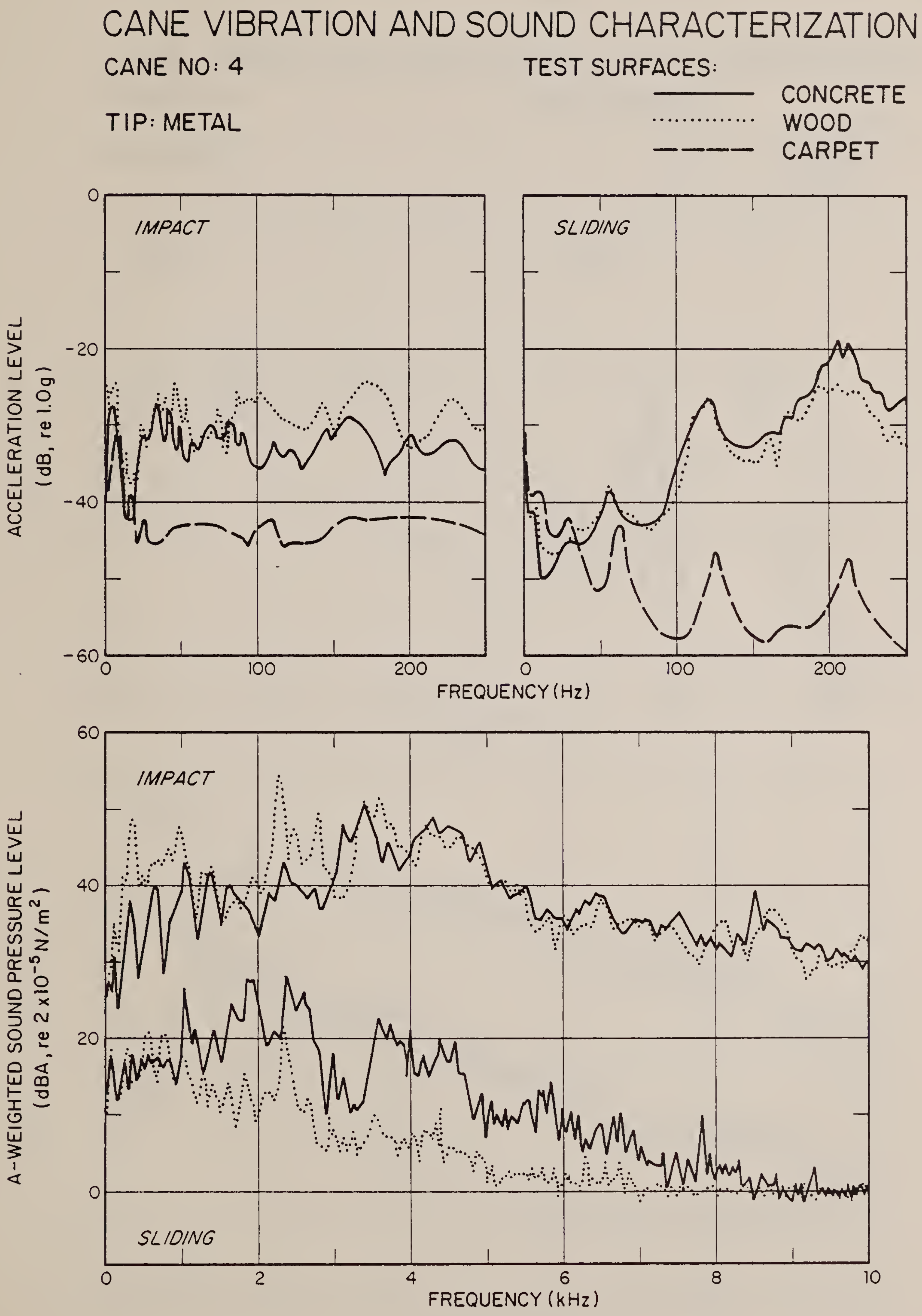


CANE VIBRATION AND SOUND CHARACTERIZATION

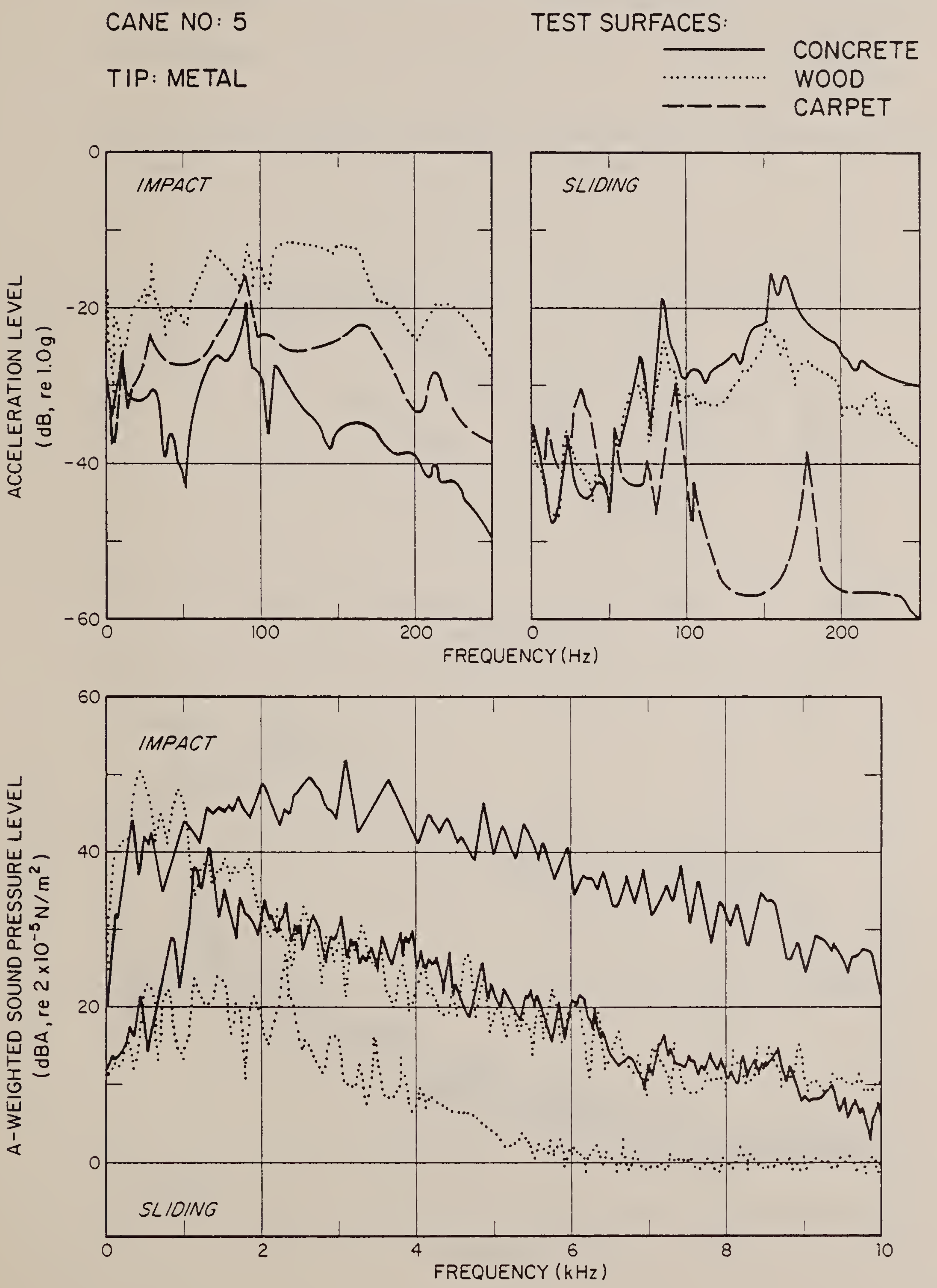
CANE NO: 3

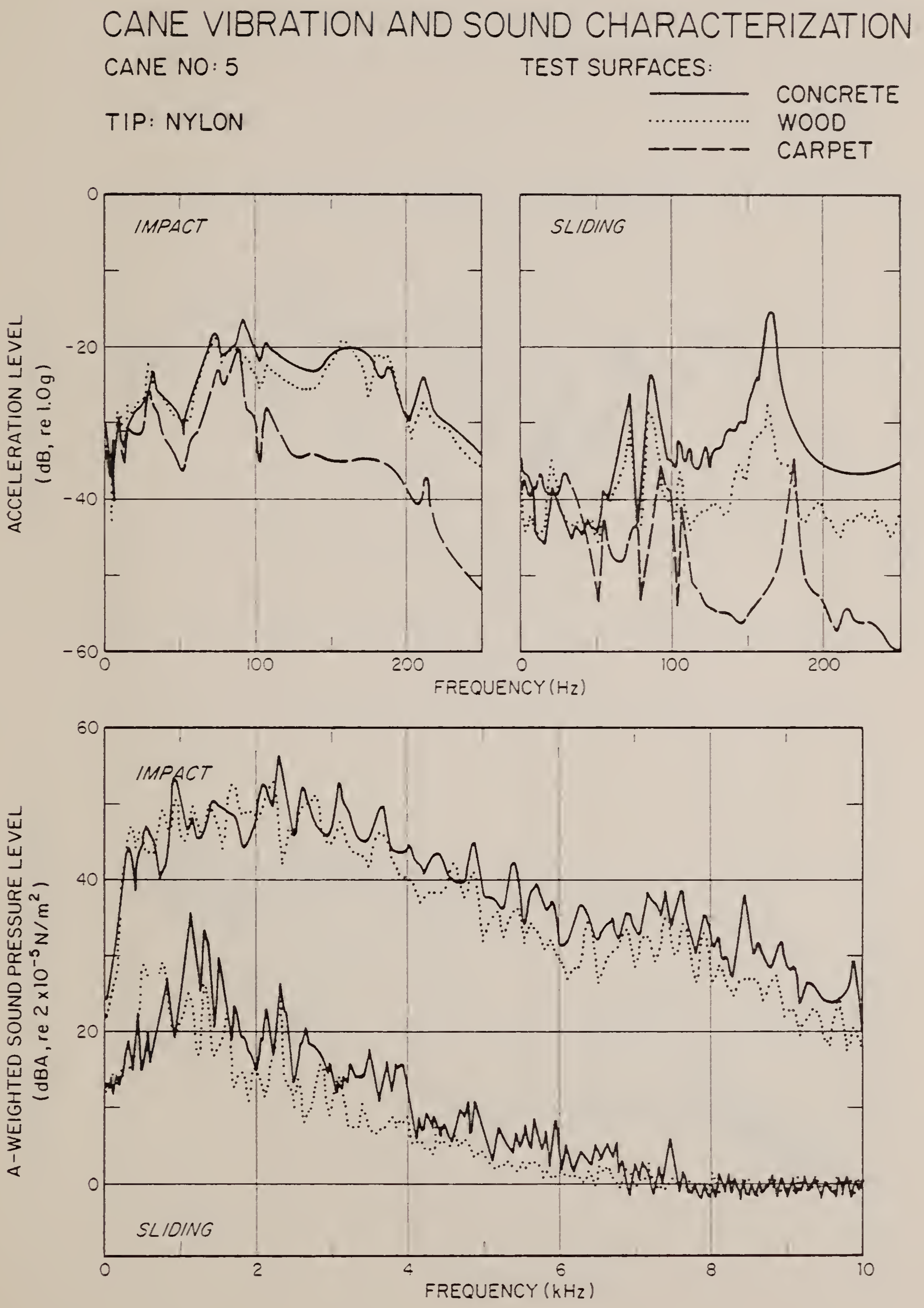
TIP: NYLON

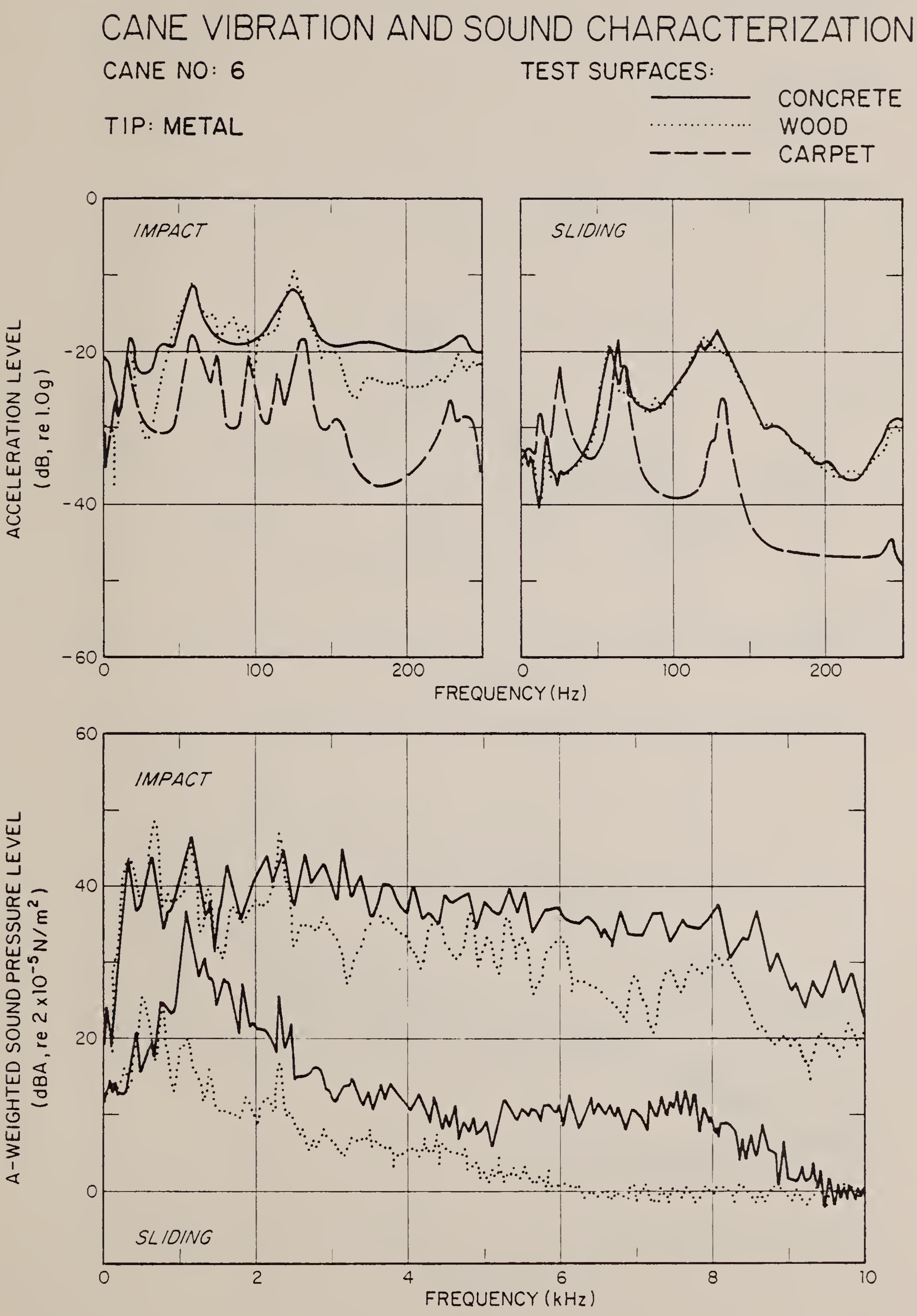
TEST SURFACES:


CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 4
TIP: METAL
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
IMPACT
SLIDING
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x 10⁻⁵ N/m²)
60
40
20
0
2
4
6
8
10
FREQUENCY (kHz)

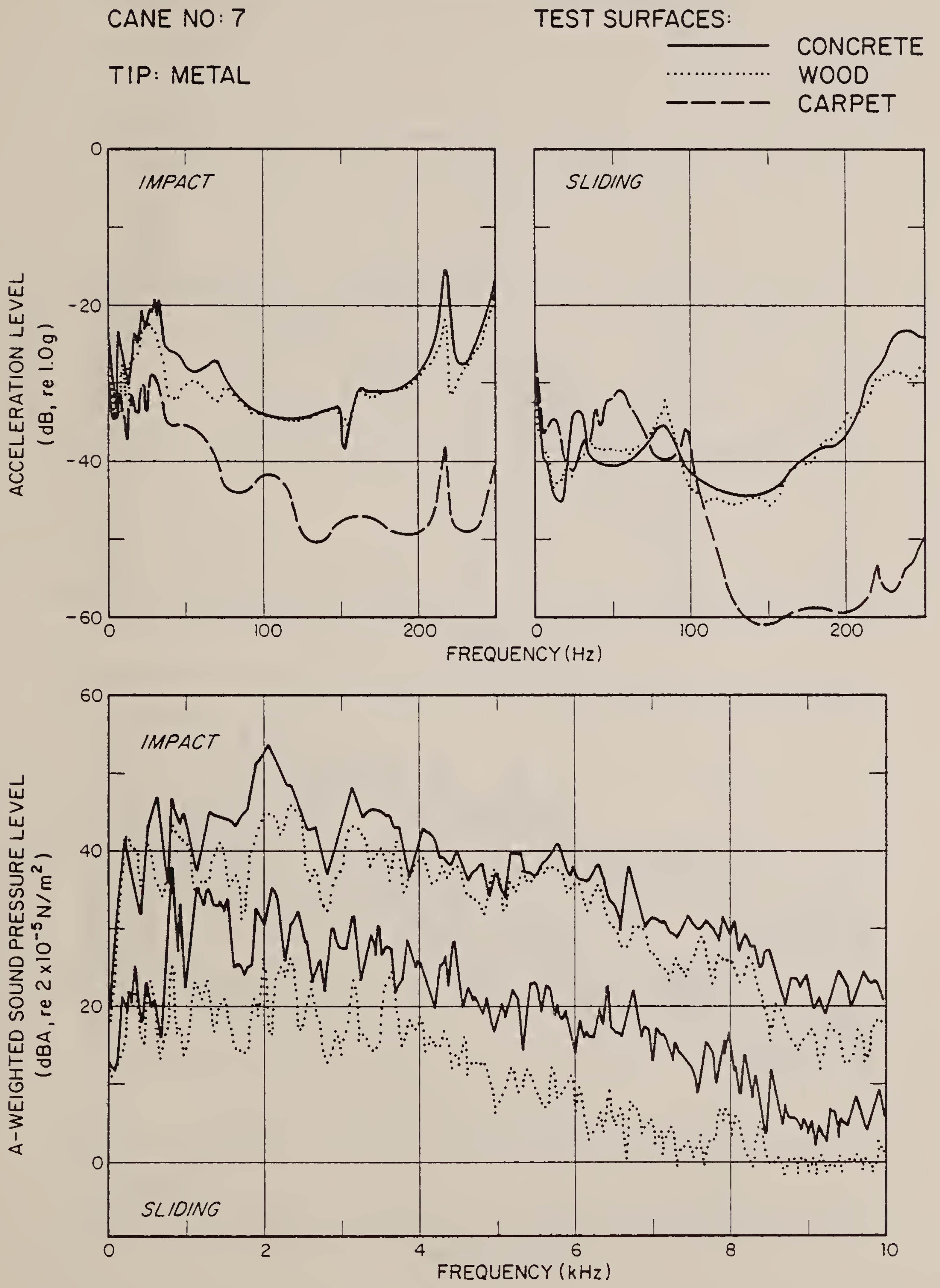
# CANE VIBRATION AND SOUND CHARACTERIZATION

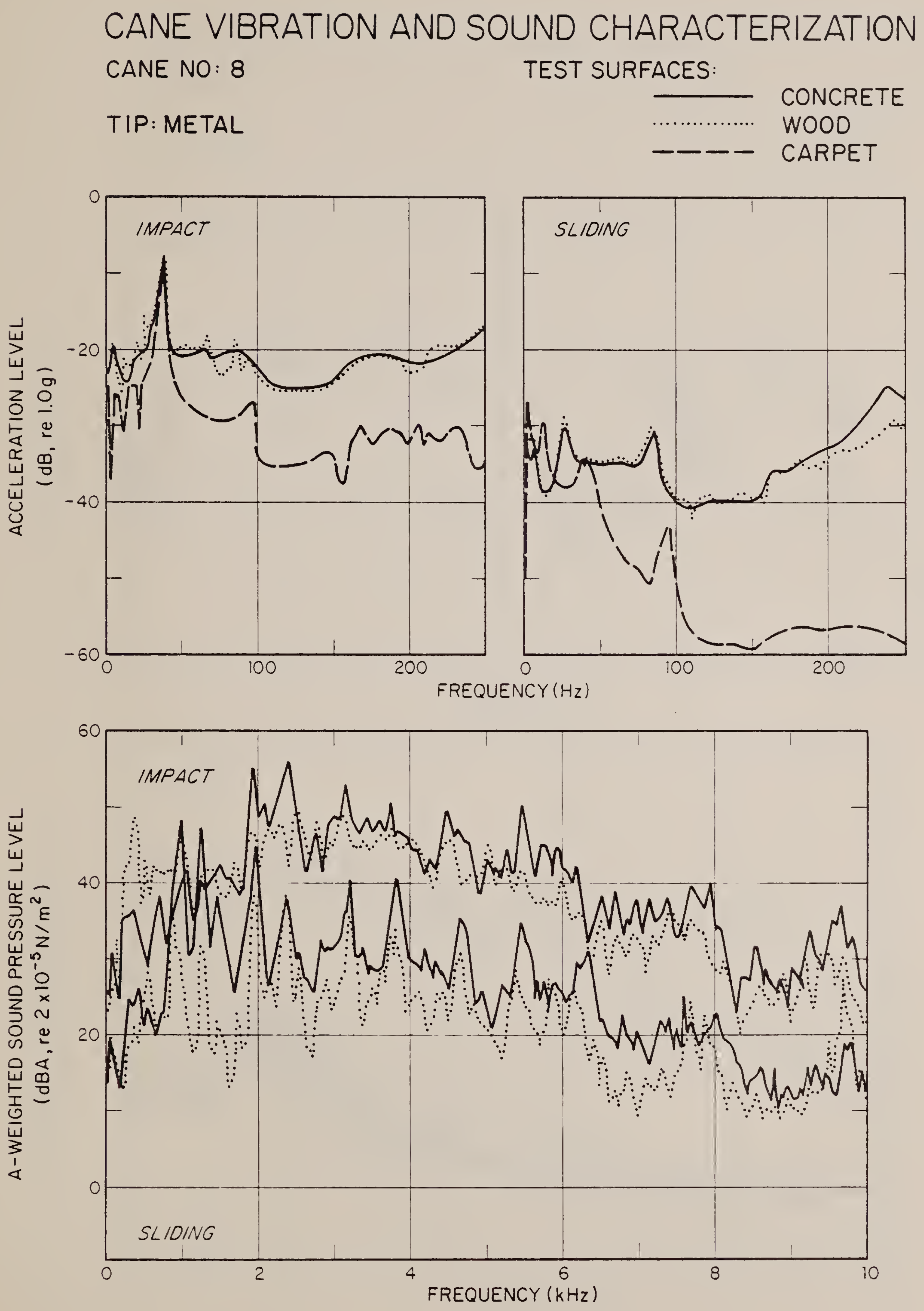


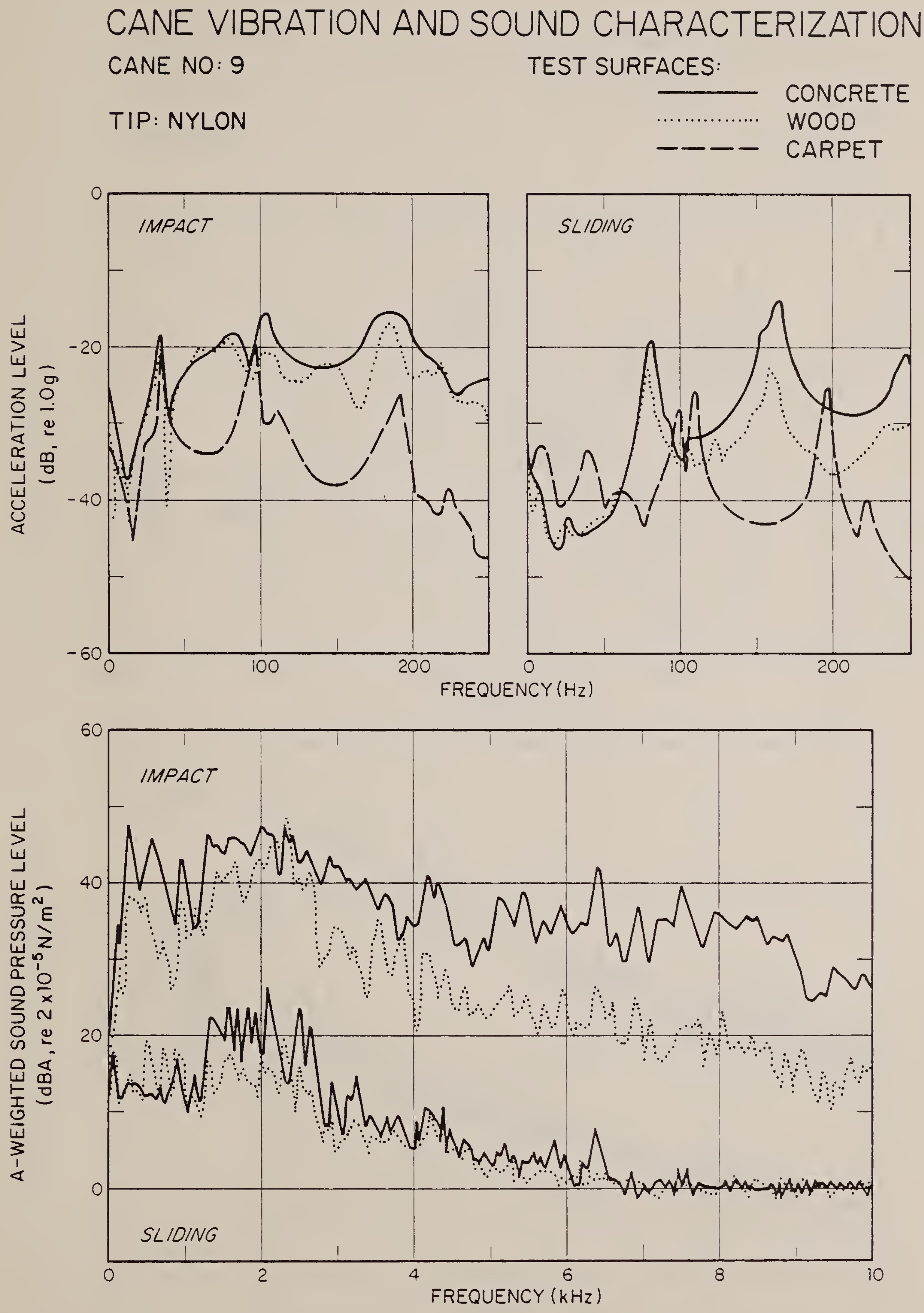

CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 5
TIP: NYLON
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x 10⁻⁵ N/m²)
60
40
20
0
IMPACT
SLIDING
0
2
4
6
8
10
FREQUENCY (kHz)


CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 6
TIP: METAL
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
IMPACT
SLIDING
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x 10^-5 N/m^2)
60
40
20
0
2
4
6
8
10
FREQUENCY (kHz)

## CANE VIBRATION AND SOUND CHARACTERIZATION




CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 8
TIP: METAL
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x 10^-5 N/m^2)
60
40
20
0
IMPACT
SLIDING
0
2
4
6
8
10
FREQUENCY (kHz)

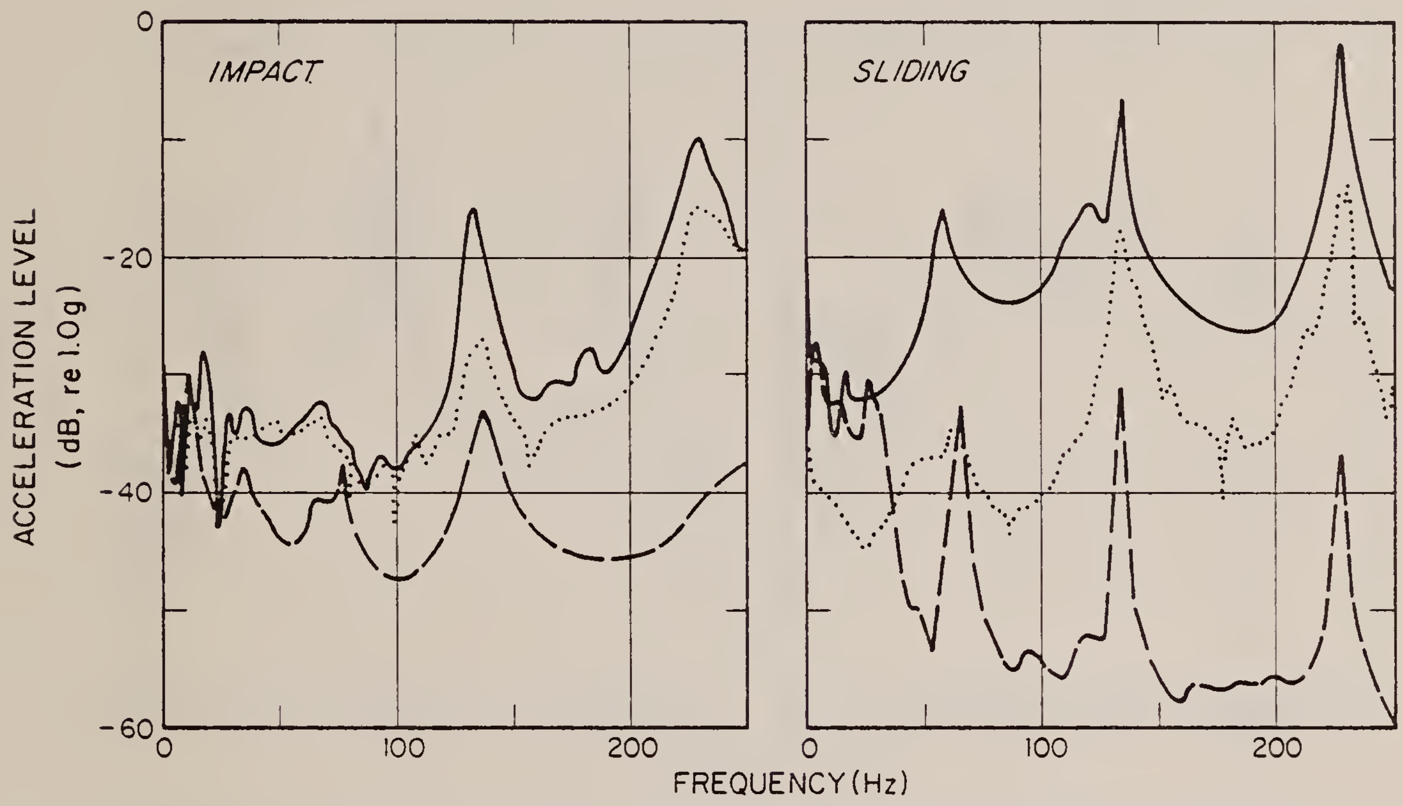

CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 9
TIP: NYLON
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
IMPACT
SLIDING
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x10⁻⁵ N/m²)
60
40
20
0
2
4
6
8
10
FREQUENCY (kHz)

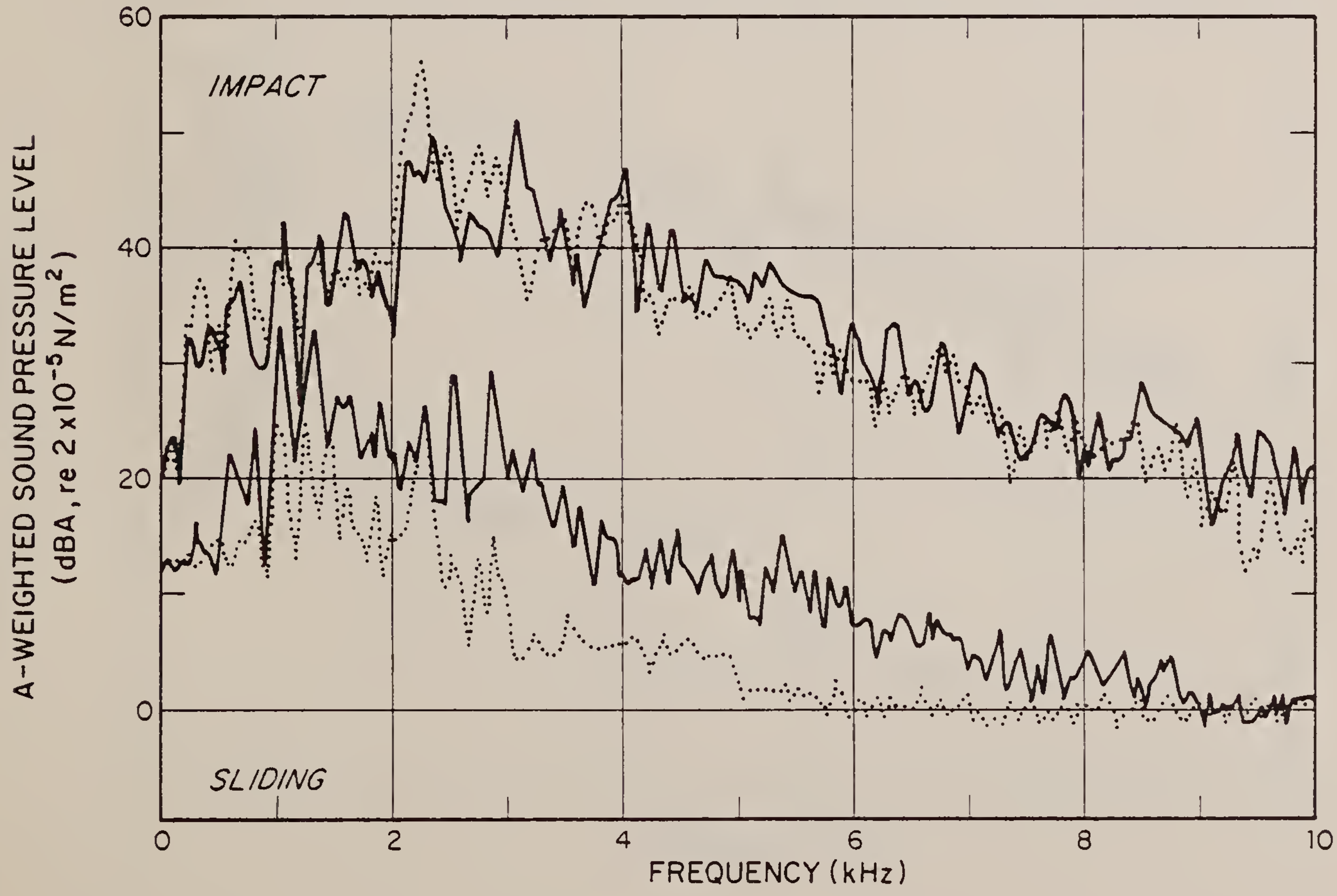
# CANE VIBRATION AND SOUND CHARACTERIZATION

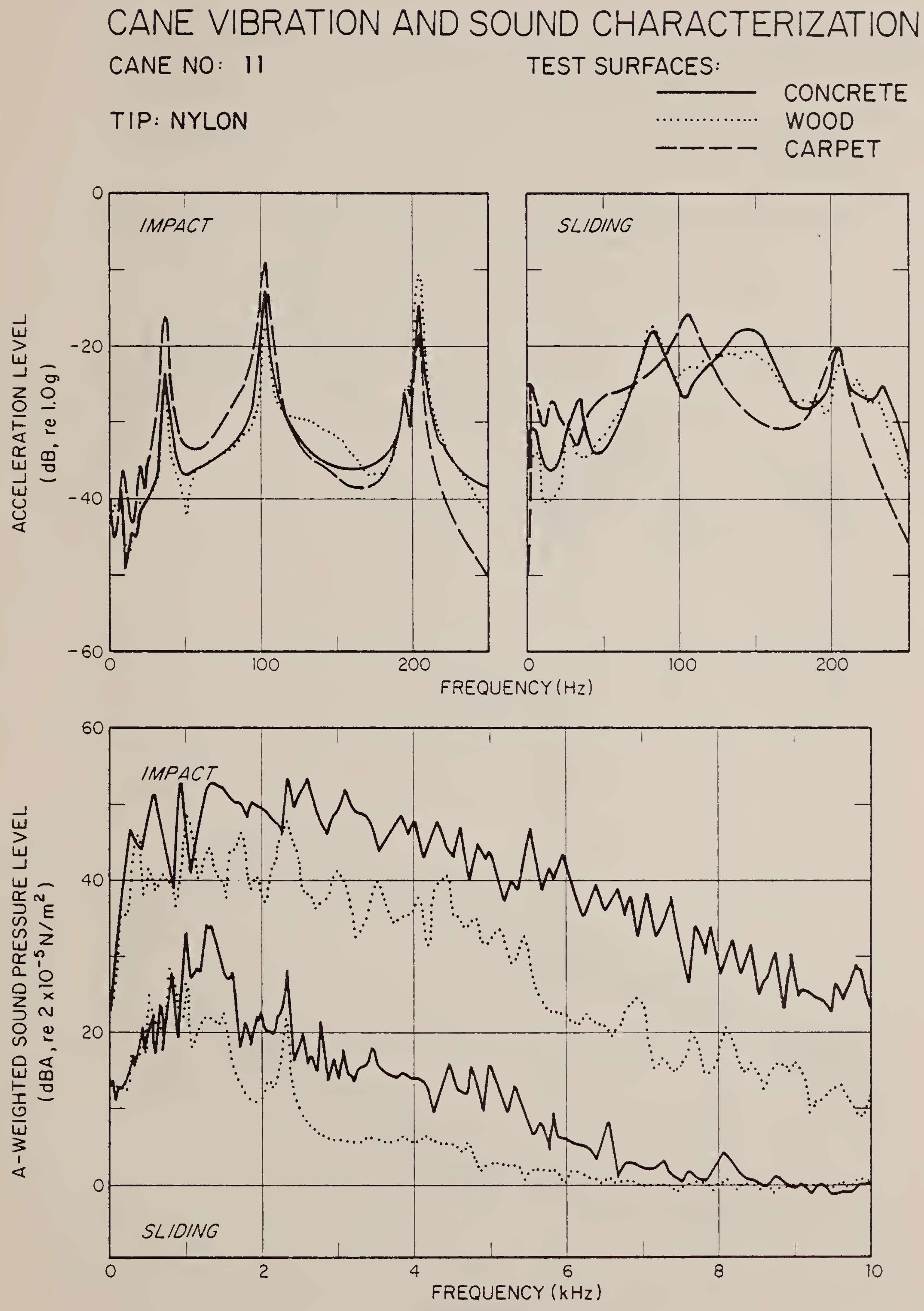
CANE NO: 10

TIP: METAL

TEST SURFACES:
——— CONCRETE
········· WOOD
– – – – CARPET






CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 11
TIP: NYLON
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x 10$^{-5}$ N/m$^2$)
60
40
20
0
IMPACT
SLIDING
0
2
4
6
8
10
FREQUENCY (kHz)

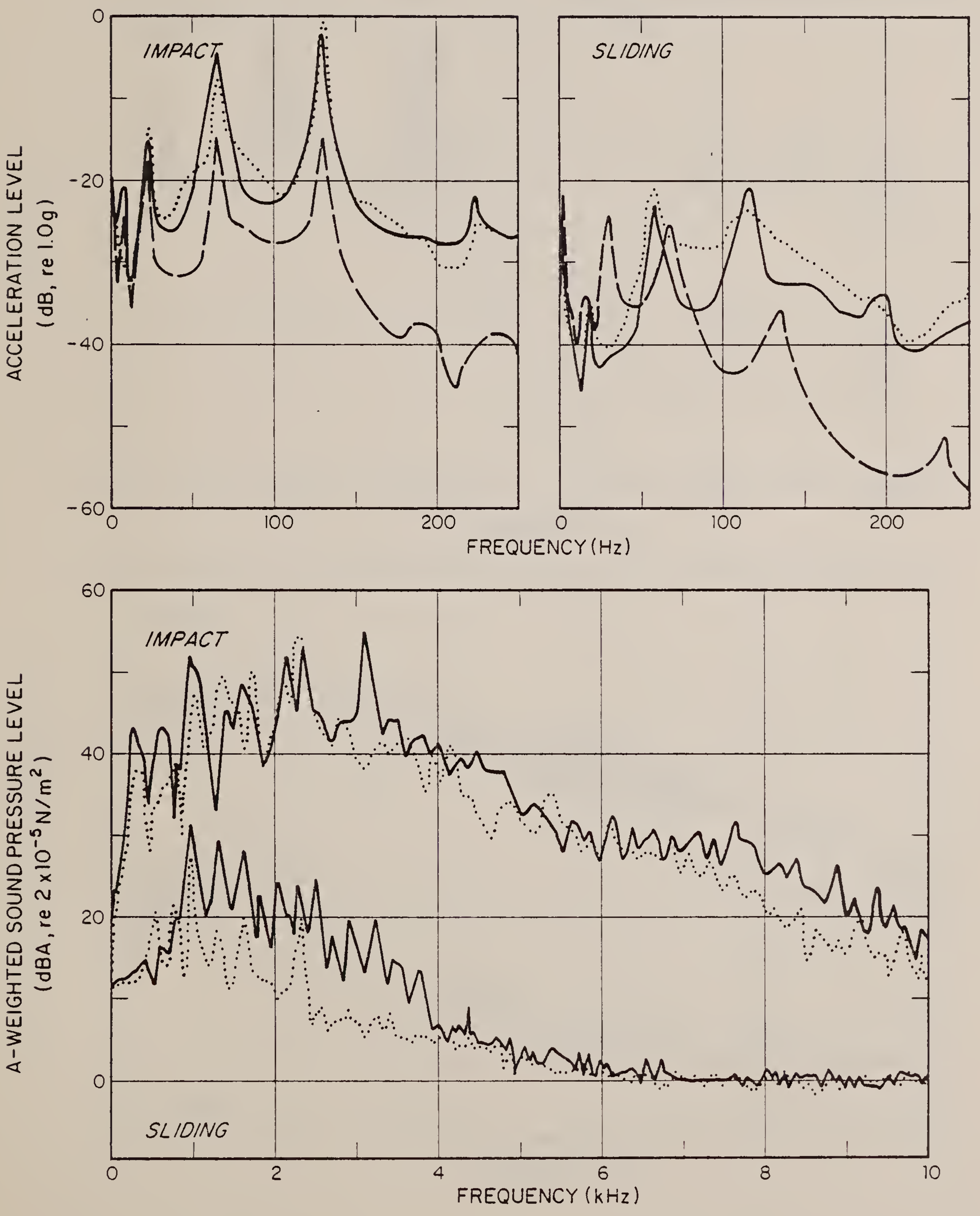
# CANE VIBRATION AND SOUND CHARACTERIZATION

CANE NO: 12

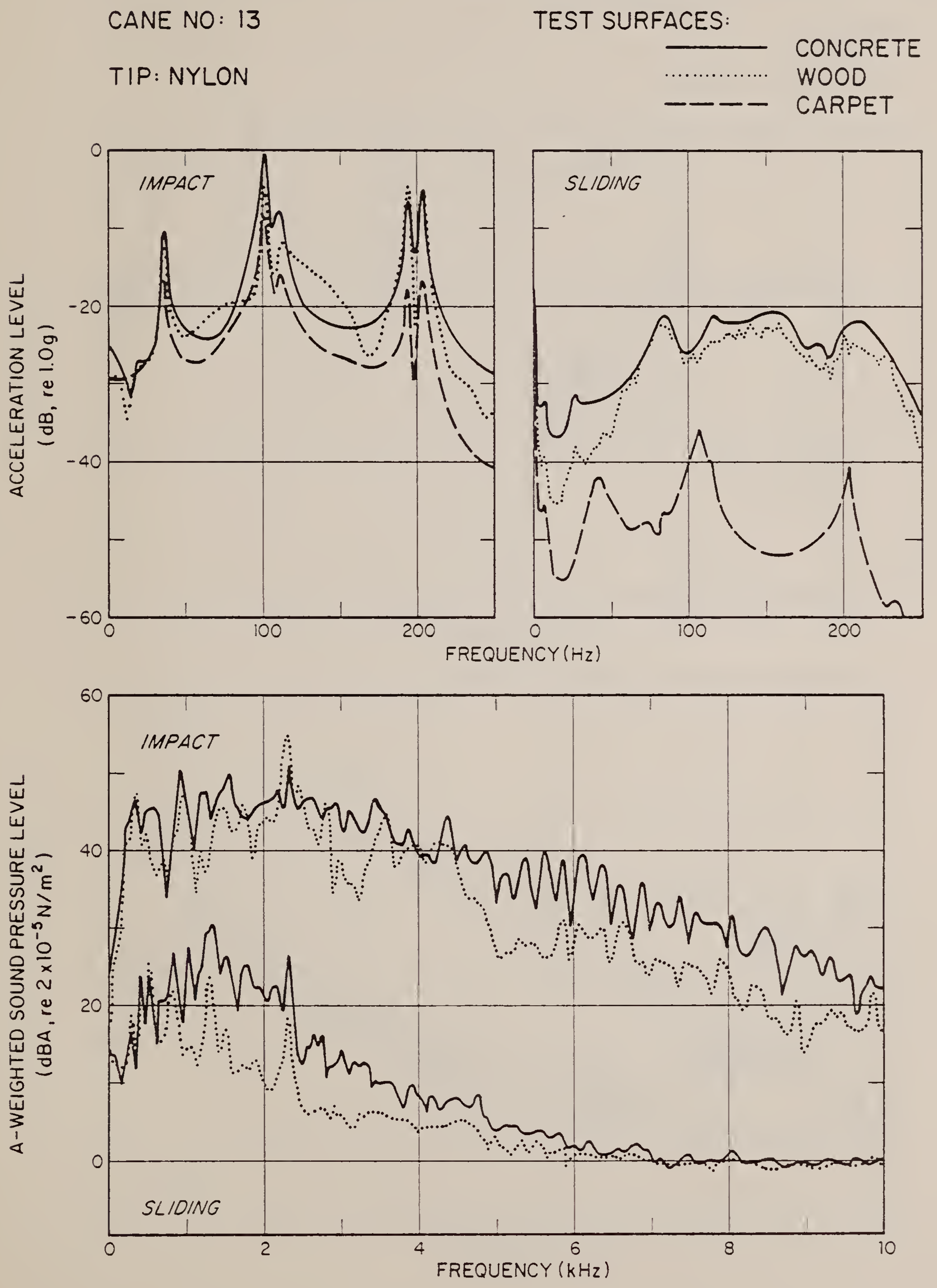
TIP: NYLON

TEST SURFACES:

——— CONCRETE
········ WOOD
— — — CARPET



## CANE VIBRATION AND SOUND CHARACTERIZATION

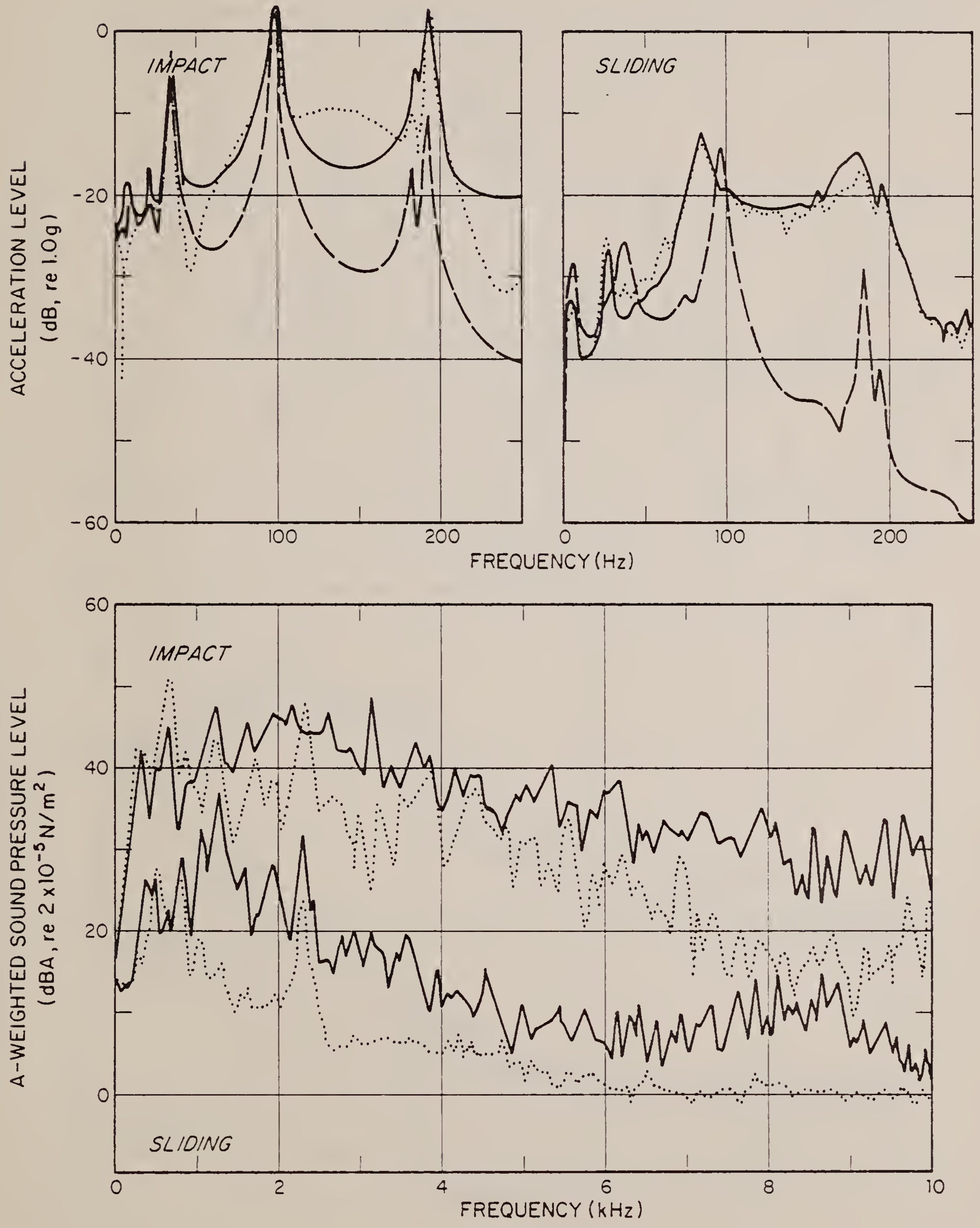


## CANE VIBRATION AND SOUND CHARACTERIZATION

CANE NO: 14

TIP: METAL

TEST SURFACES:
——— CONCRETE
·········· WOOD
– – – – CARPET



# CANE VIBRATION AND SOUND CHARACTERIZATION

CANE NO: 15

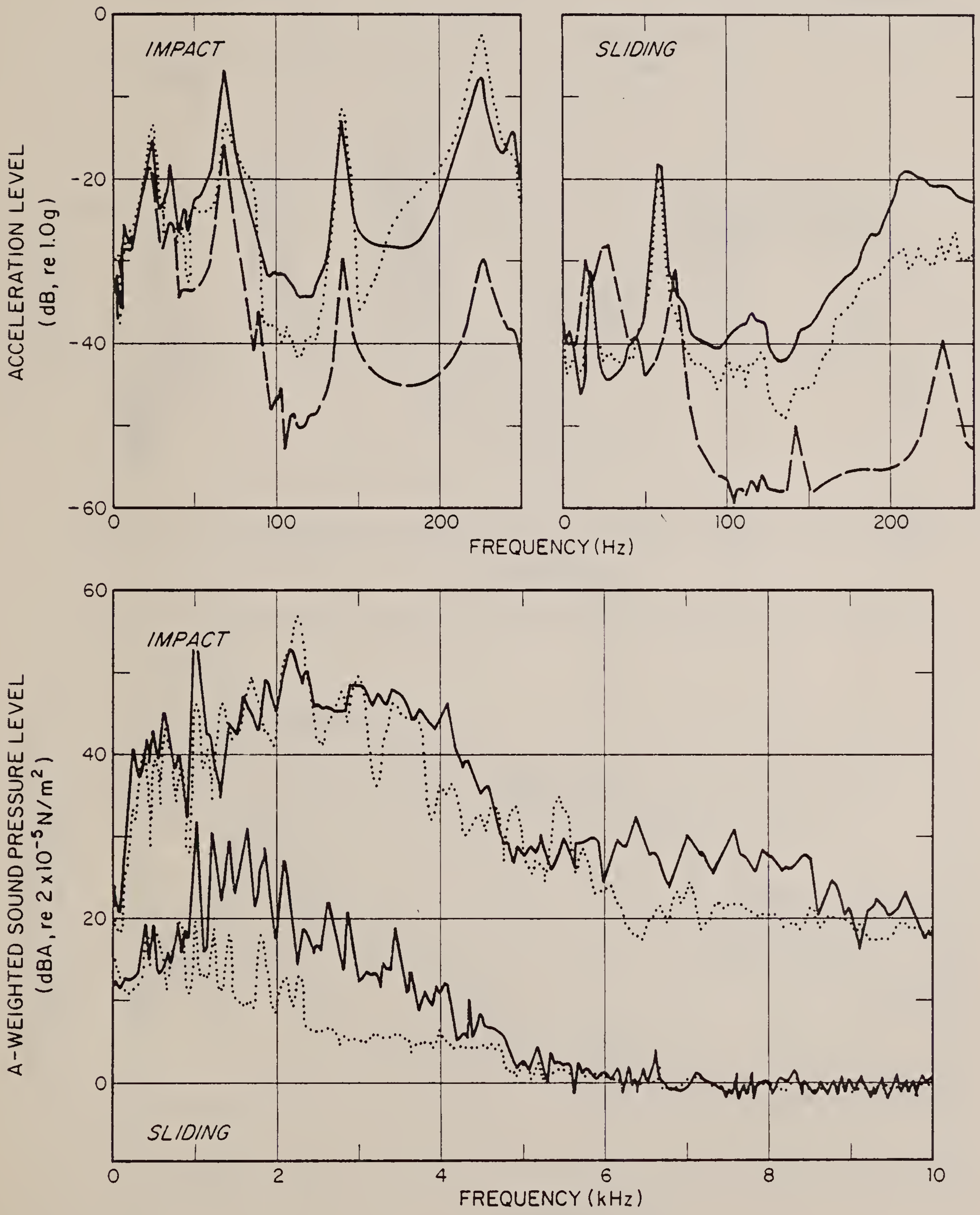
TIP: NYLON

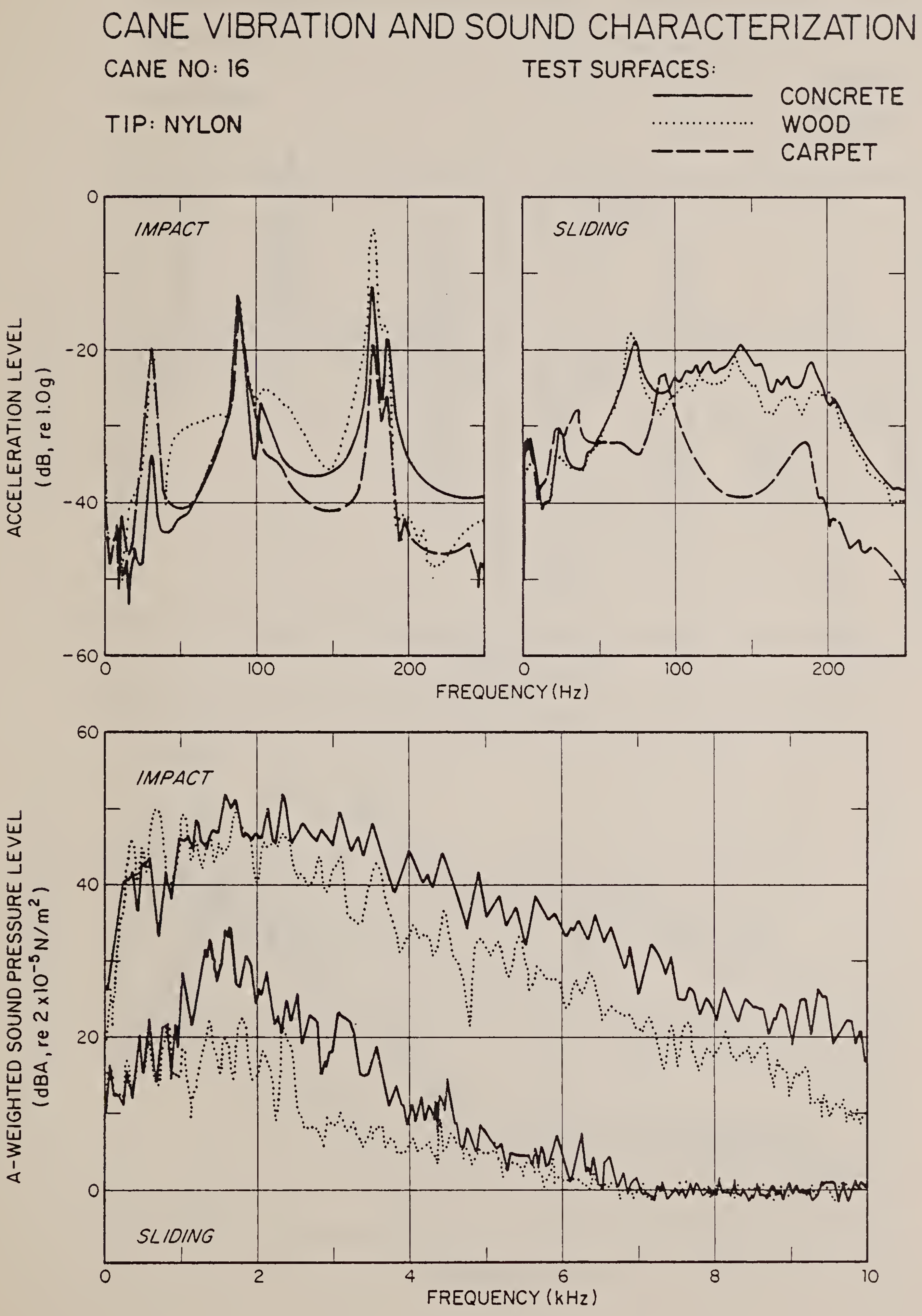
TEST SURFACES:

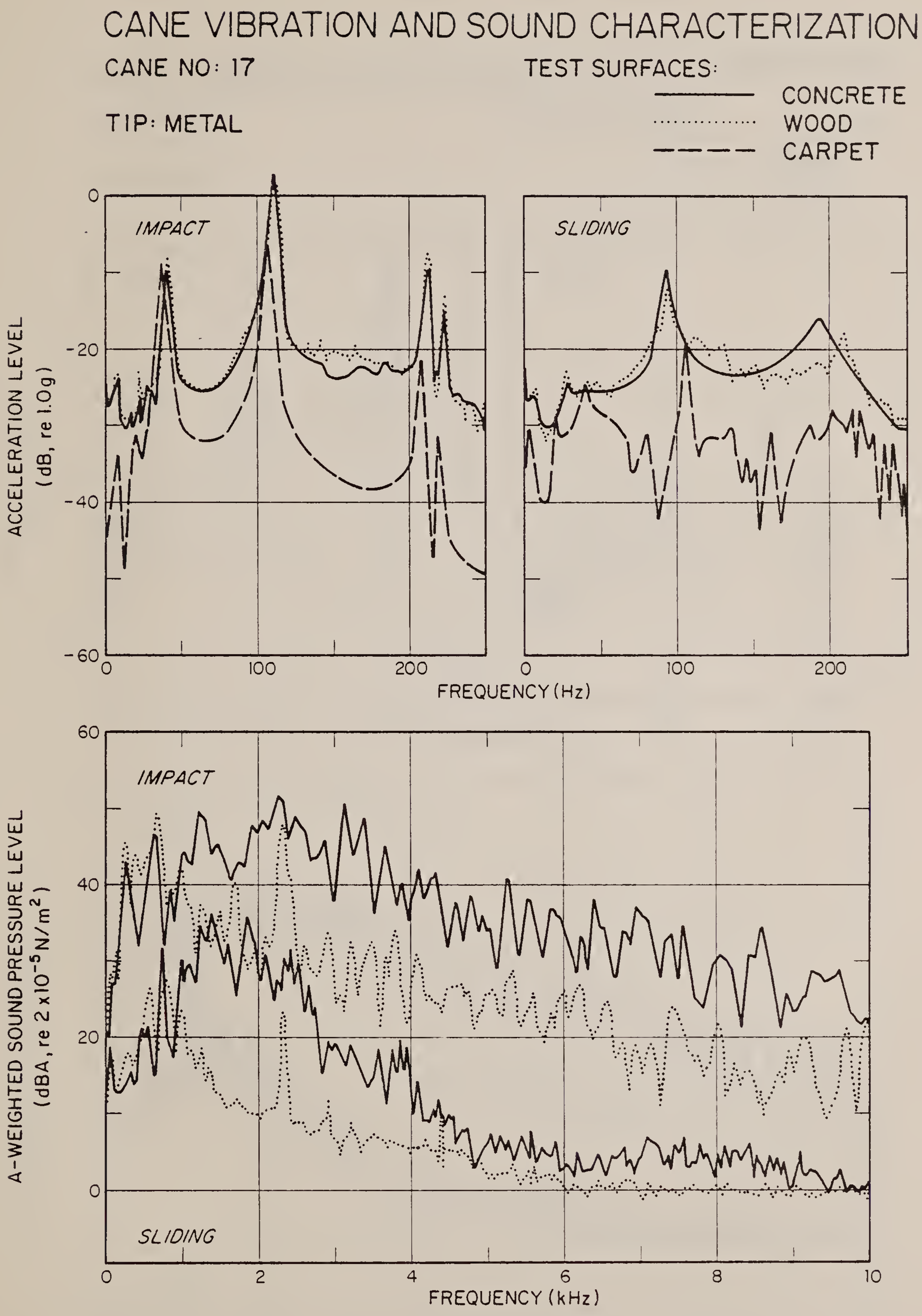
—— CONCRETE

······ WOOD

— — CARPET




CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 16
TIP: NYLON
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
IMPACT
SLIDING
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x10$^{-5}$ N/m$^{2}$)
60
40
20
0
2
4
6
8
10
FREQUENCY (kHz)


CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 17
TIP: METAL
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
IMPACT
SLIDING
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x 10^-5 N/m^2)
60
40
20
0
0
2
4
6
8
10
FREQUENCY (kHz)

# CANE VIBRATION AND SOUND CHARACTERIZATION

CANE NO: 18

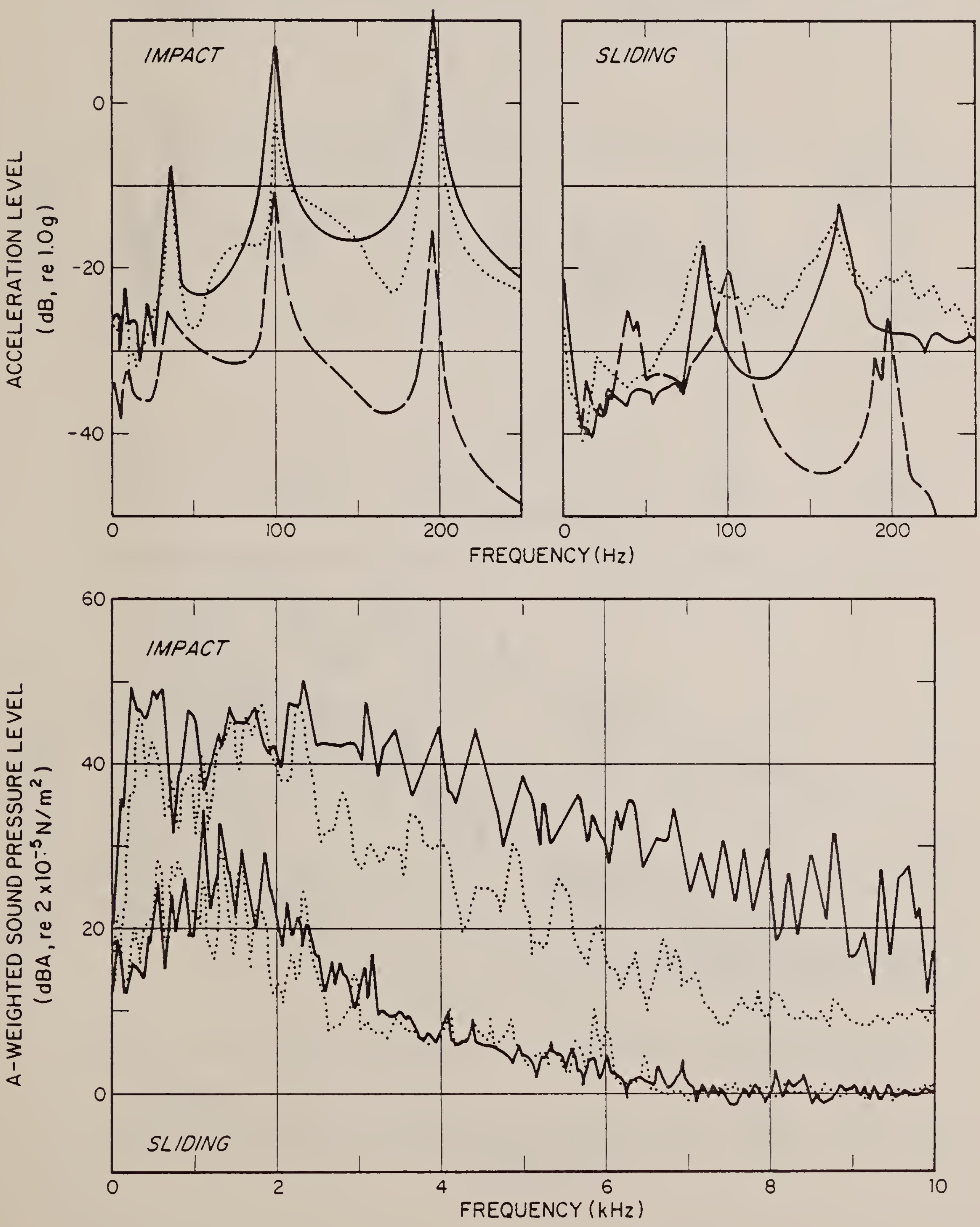
TIP: NYLON

TEST SURFACES:

——— CONCRETE

········ WOOD

— — — CARPET



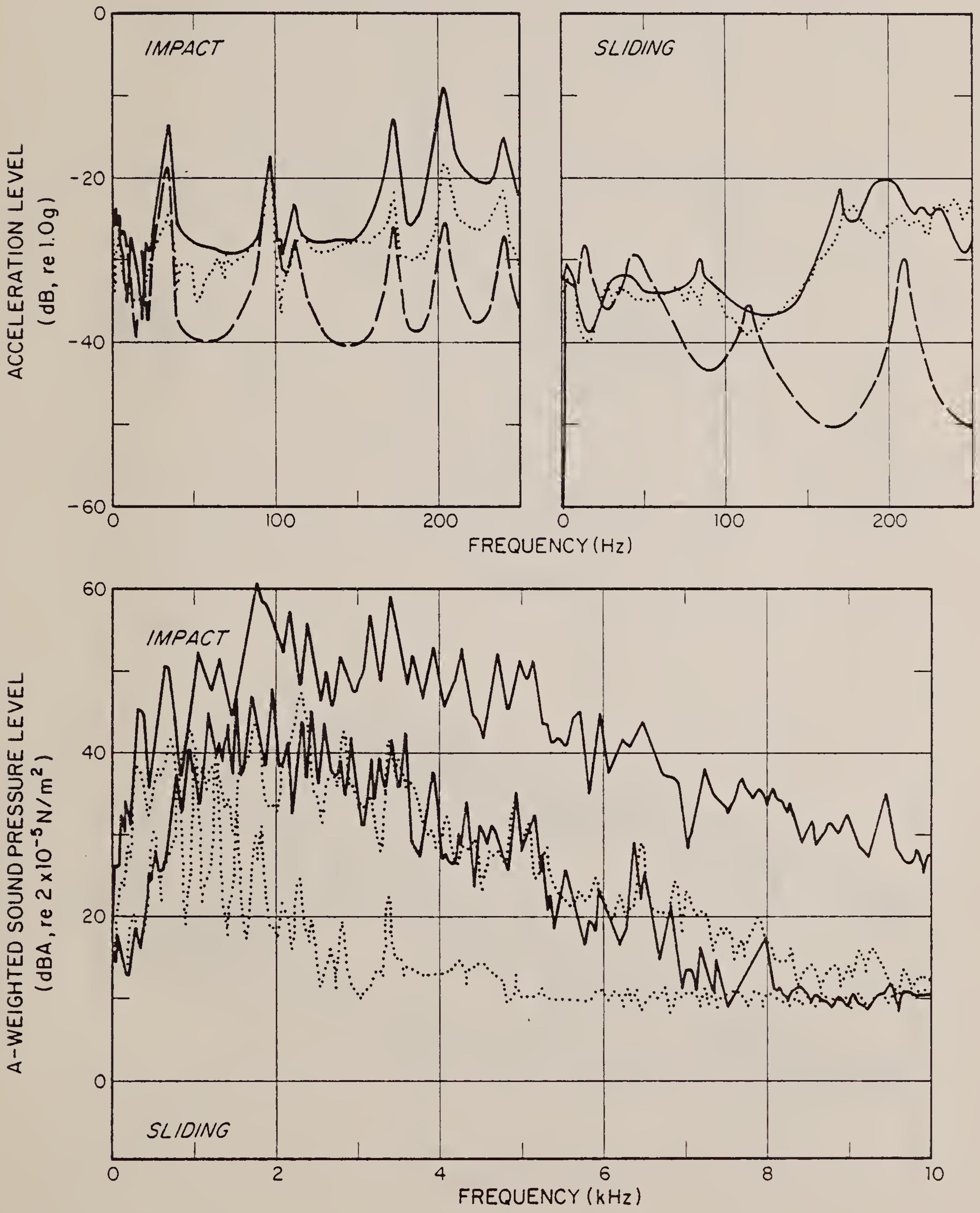
## CANE VIBRATION AND SOUND CHARACTERIZATION

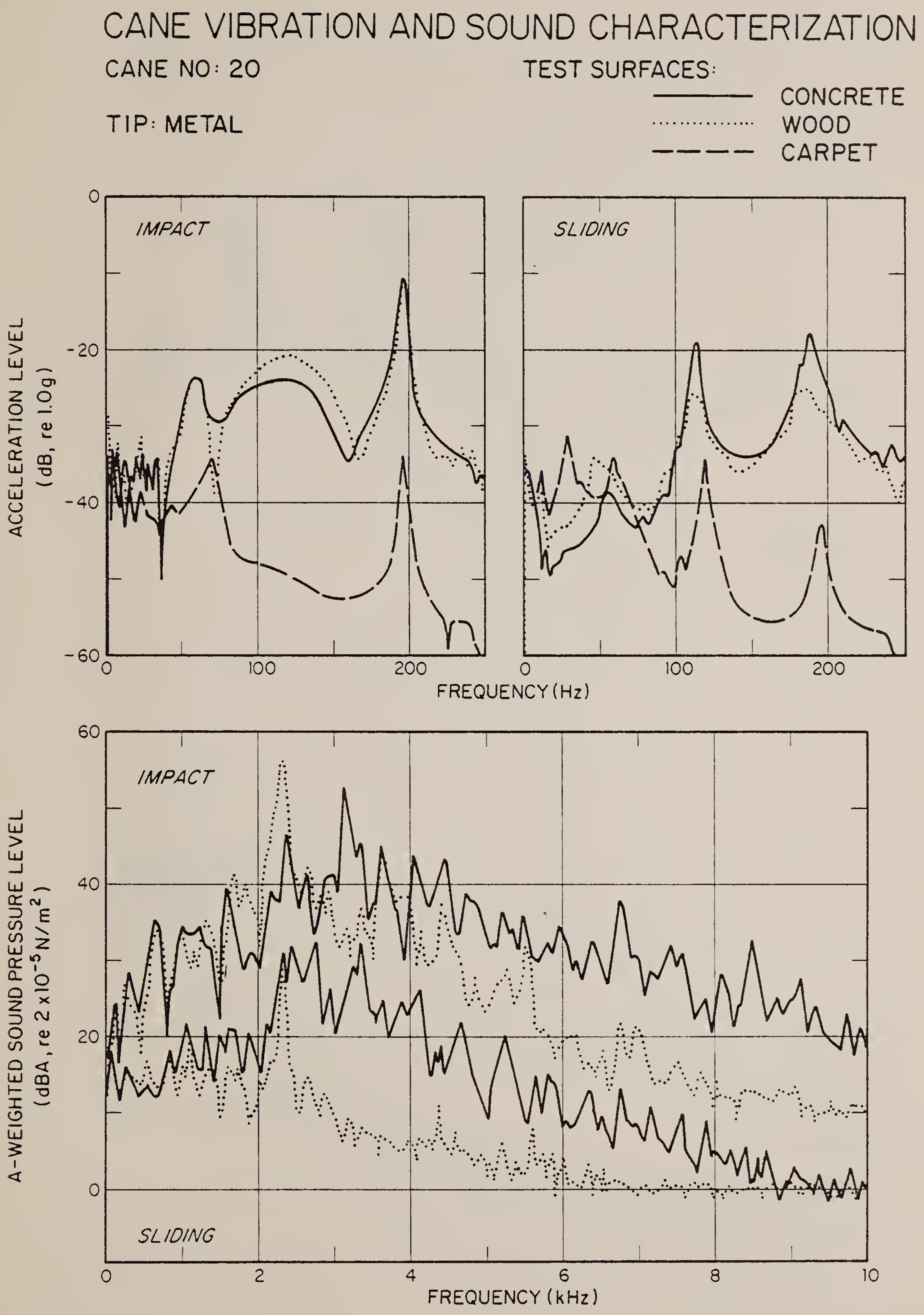
CANE NO: 19

TIP: METAL

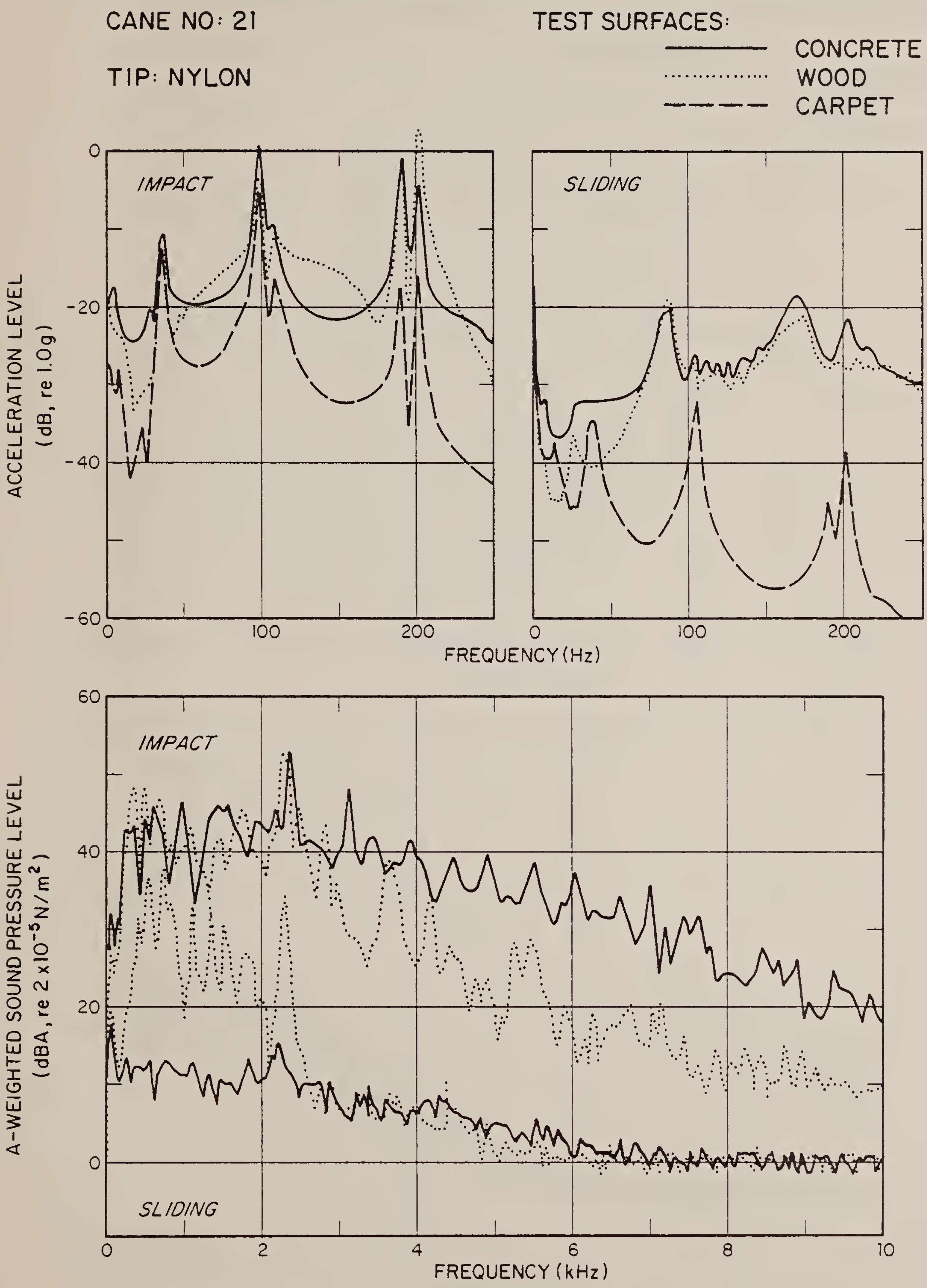
TEST SURFACES:

——— CONCRETE
·········· WOOD
— — — CARPET




CANE VIBRATION AND SOUND CHARACTERIZATION
CANE NO: 20
TIP: METAL
TEST SURFACES:
CONCRETE
WOOD
CARPET
IMPACT
SLIDING
ACCELERATION LEVEL (dB, re 1.0g)
0
-20
-40
-60
0
100
200
FREQUENCY (Hz)
IMPACT
SLIDING
A-WEIGHTED SOUND PRESSURE LEVEL (dBA, re 2 x 10$^{-5}$ N/m$^2$)
60
40
20
0
2
4
6
8
10
FREQUENCY (kHz)

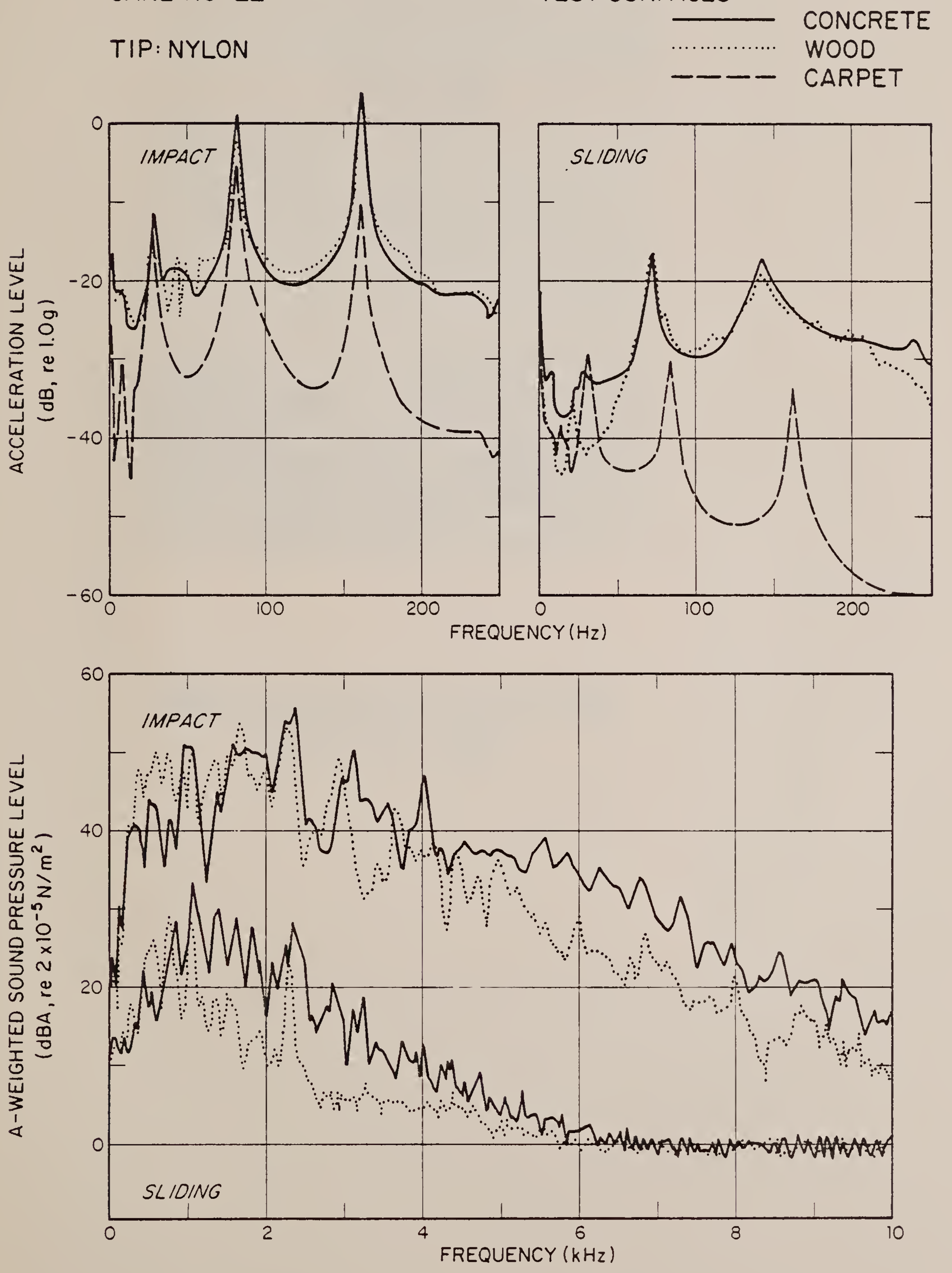
## CANE VIBRATION AND SOUND CHARACTERIZATION



## CANE VIBRATION AND SOUND CHARACTERIZATION

CANE NO: 22

TIP: NYLON



HV1708
Un3 Ungar, Eric E
Sound and
vibration
characterization

DATE DUE

HV1708
Un3 Ungar, Eric E
Sound and
vibration

| DATE | ISSUED TO |
|---|---|
| 6/22 | Adele Piontrica 1440 50th St.<br>436-1474 |
| 5/8/91 | Robinson Street<br>901 Washington<br>Avenue. |
| 05 08-3 | B.K. NY 1122[illegible] |

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